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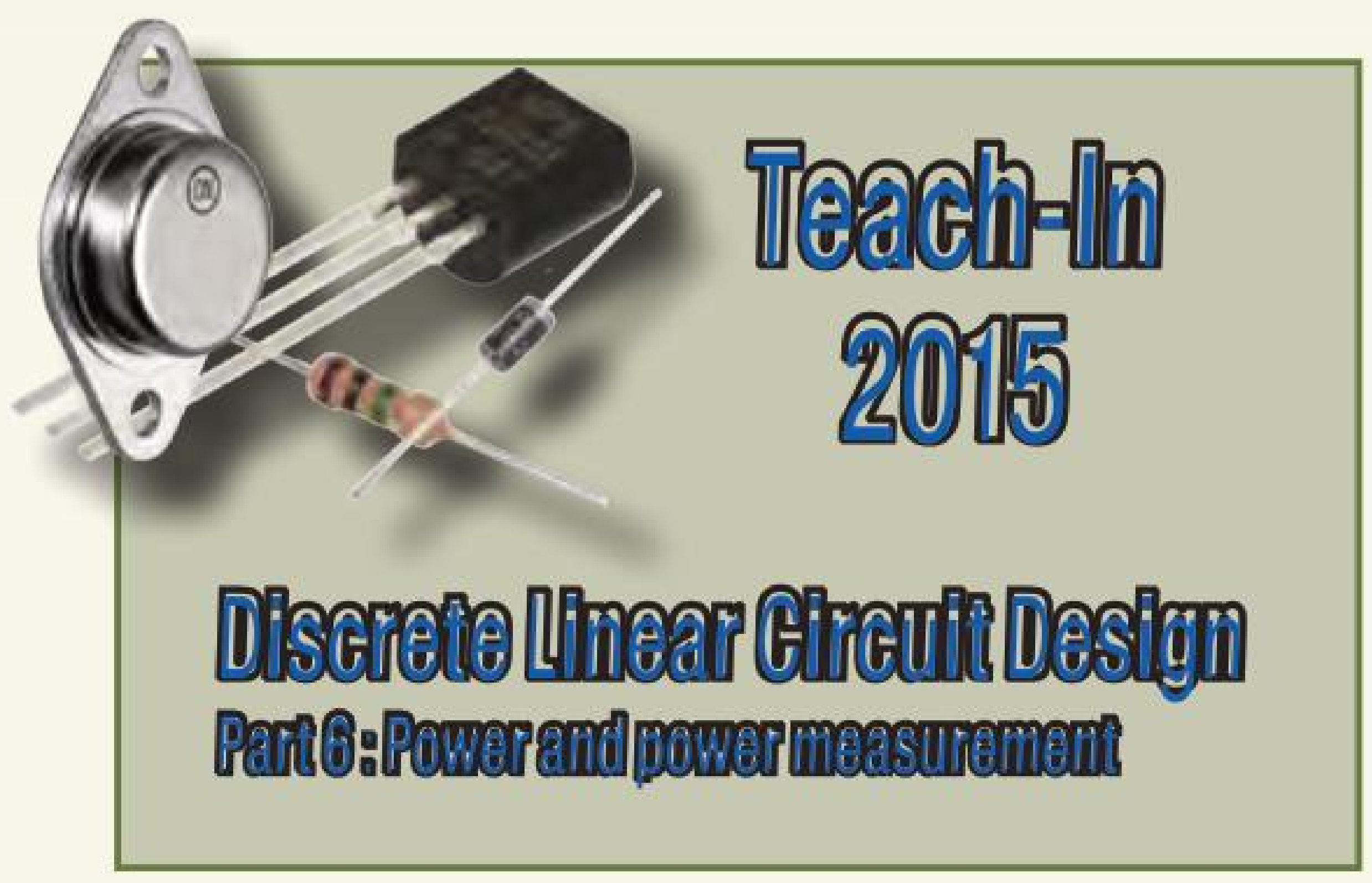
Teach-In
2015
Discrete Linear Circuit Design
Part 6: Power and power measurement

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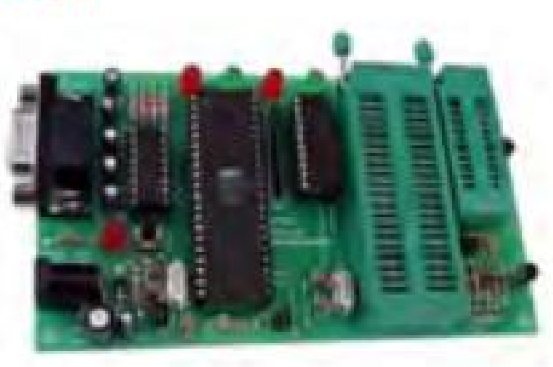

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*Kit Order Code: 3123KT - **£28.95***
*Assembled Order Code: AS3123 - **£39.95***

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*Kit Order Code: K8048 - **£23.94***
*Assembled Order Code: VM111 - **£39.12***

Controllers & Loggers

Here are just a few of the controller and data acquisition and control units we have. See website for full details. 12Vdc PSU for all units: Order Code 660.446UK £11.52

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5 digital input channels and 8 digital output channels plus two analogue inputs and two analogue outputs with 8 bit resolution.
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*Kit Order Code: 8157KT - **£49.95***
*Assembled Order Code: AS8157 - **£54.95***

Computer Temperature Data Logger

Serial port 4-channel temperature logger. °C or °F. Continuously logs up to 4 separate sensors located 200m+ from board. Wide range of free software applications for storing/using data. PCB just 45x45mm. Powered by PC. Includes one DS1820 sensor.
*Kit Order Code: 3145KT - **£19.95***
*Assembled Order Code: AS3145 - **£26.95***
*Additional DS1820 Sensors - **£4.95 each***

Remote Control Via GSM Mobile Phone

Place next to a mobile phone (not included). Allows toggle or auto-timer control of 3A mains rated output relay from any location

Most items are available in kit form (KT suffix) or pre-assembled and ready for use (AS prefix).

4-Ch DTMF Telephone Relay Switcher

Call your phone number using a DTMF phone from anywhere in the world and remotely turn on/off any of the 4 relays as desired. User settable Security Password, Anti-Tamper, **Rings** to Answer, Auto Hang-up and Lockout. Includes plastic case. 130 x 110 x 30mm. Power: 12Vdc.
*Kit Order Code: 3140KT - **£79.95***
*Assembled Order Code: AS3140 - **£94.95***

8-Ch Serial Port Isolated I/O Relay Module

Computer controlled 8 channel relay board. 5A mains rated relay outputs and 4 opto-isolated digital inputs (for monitoring switch states, etc). Useful in a variety of control and sensing applications. Programmed via serial port (use our new Windows interface, terminal emulator or batch files). Serial cable can be up to 35m long. Includes plastic case 130x100x30mm. Power: 12Vdc/500mA.
*Kit Order Code: 3108KT - **£74.95***
*Assembled Order Code: AS3108 - **£89.95***

Infrared RC 12–Channel Relay Board

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*Kit Order Code: 3153KT - **£37.95***
*Assembled Order Code: AS3153 - **£49.95***

3x5Amp RGB LED Controller with RS232

3 independent high power channels. Preprogrammed or user-editable light sequences. Standalone option and 2-wire serial interface for microcontroller or PC communication with simple command set. Suitable for common anode RGB LED strips, LEDs and incandescent bulbs. 56 x 39 x 20mm. 12A total max. Supply: 12Vdc.
Kit Order Code: 8191KT - £29.95
Assembled Order Code: AS8191 - £39.95

Hot New Products!

Here are a few of the most recent products added to our range. See website or join our email Newsletter for all the latest news.

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Assembled Order Code: AS3190 - ***£99.95***

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Bipolar Stepper Motor Chopper Driver

Get better performance from your stepper motors with this dual full bridge motor driver based on SGS Thompson chips L297 & L298. Motor current for each phase set using on-board potentiometer. Rated to handle motor winding currents up to 2 Amps per phase. Operates on 9-36Vdc supply voltage. Provides all basic motor controls including full or half stepping of bipolar steppers and direction control. Allows multiple driver synchronisation. Perfect for desktop CNC applications.
Kit Order Code: 3187KT - ***£39.95***
Assembled Order Code: AS3187 - ***£49.95***

Video Signal Cleaner

Digitally cleans the video signal and removes unwanted distortion in video signal. In addition it stabilises picture quality and luminance fluctuations. You will also benefit from improved picture quality on LCD monitors or projectors.
Kit Order Code: K8036 - ***£24.70***
Assembled Order Code: VM106 - ***£36.53***

Motor Speed Controllers

Here are just a few of our controller and driver modules for AC, DC, Unipolar/Bipolar stepper motors and servo motors. See website for full details.

DC Motor Speed Controller (100V/7.5A)

Control the speed of almost any common DC motor rated up to 100V/7.5A. Pulse width modulation output for maximum motor torque at all speeds. Supply: 5-15Vdc. Box supplied. Dimensions (mm): 60Wx100Lx60H.
Kit Order Code: 3067KT - ***£19.95***
Assembled Order Code: AS3067 - ***£27.95***

Bidirectional DC Motor Speed Controller

Control the speed of most common DC motors (rated up to 32Vdc/10A) in both the forward and reverse direction. The range of control is from fully OFF to fully ON in both directions. The direction and speed are controlled using a single potentiometer. Screw terminal block for connections.
Kit Order Code: 3166v2KT - ***£23.95***
Assembled Order Code: AS3166v2 - ***£33.95***

Computer Controlled / Standalone Unipolar Stepper Motor Driver

Drives any 5-35Vdc 5, 6 or 8-lead unipolar stepper motor rated up to 6 Amps. Provides speed and direction control. Operates in stand-alone or PC-controlled mode for CNC use. Connect up to six 3179 driver boards to a single parallel port. Board supply: 9Vdc. PCB: 80x50mm.
Kit Order Code: 3179KT - ***£17.95***
Assembled Order Code: AS3179 - ***£24.95***

Computer Controlled Bi-Polar Stepper Motor Driver

Drive any 5-50Vdc, 5 Amp bi-polar stepper motor using externally supplied 5V levels for STEP and DIRECTION control. Opto-isolated inputs make it ideal for CNC applications using a PC running suitable software. Board supply: 8-30Vdc. PCB: 75x85mm.
Kit Order Code: 3158KT - ***£24.95***
Assembled Order Code: AS3158 - ***£34.95***

AC Motor Speed Controller (600W)

Reliable and simple to install project that allows you to adjust the speed of an electric drill or 230V AC single phase induction motor rated up to 600 Watts. Simply turn the potentiometer to adjust the motors RPM. PCB: 48x65mm. Not suitable for use with brushless AC motors.
Kit Order Code: 1074KT - ***£15.95***
Assembled Order Code: AS1074 - ***£23.95***

See website for lots more DC, AC and stepper motor drivers!

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PROJECTS • Active RF Detector Probe For DMMs • Add A UHF Link To A Universal Remote Control • PCBirdies • USB Port Voltage Checker • iPod Charger Adaptor •

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FEATURES • Make Your Own PCBs – Part 1 • Techno Talk • Practically Speaking • Circuit Surgery • PIC n’ Mix • Net Work • Audio Out • Max’s Cool Beans •

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NOV ’14

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DEC ’14

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JAN ’15

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APR ’15

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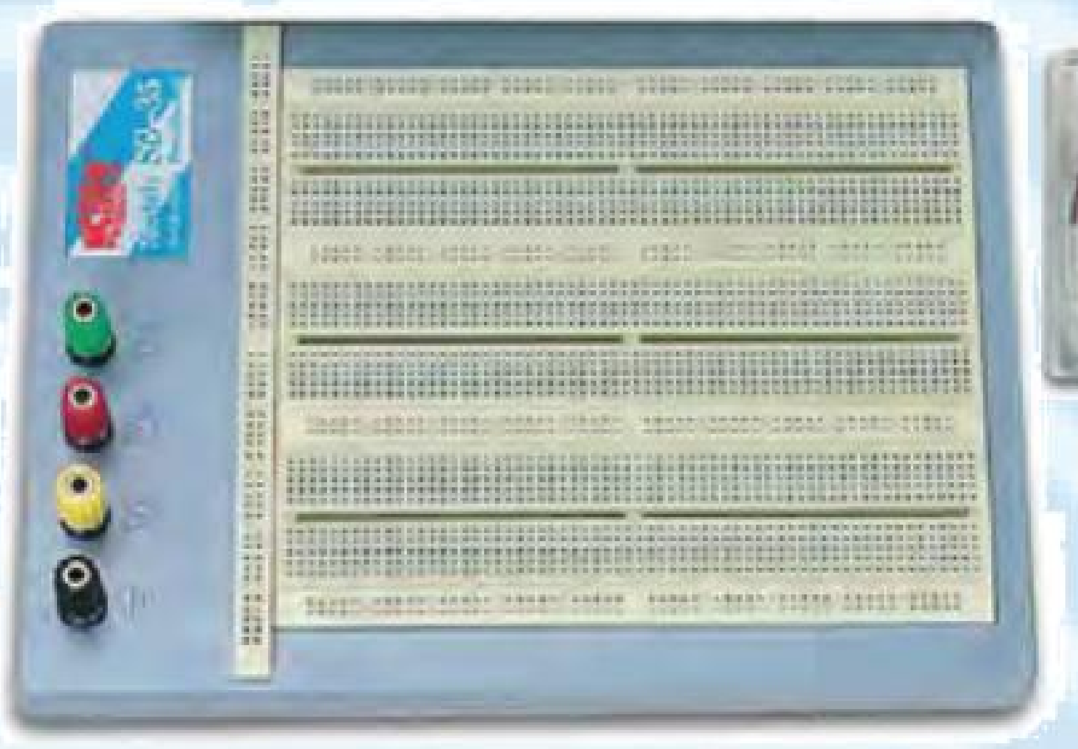

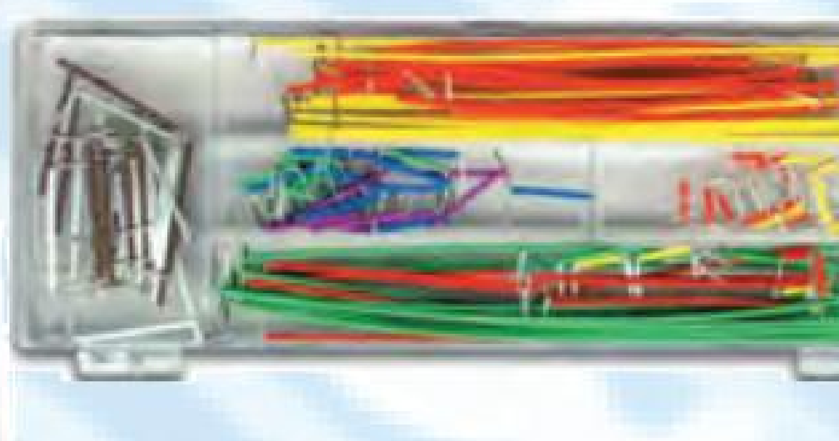

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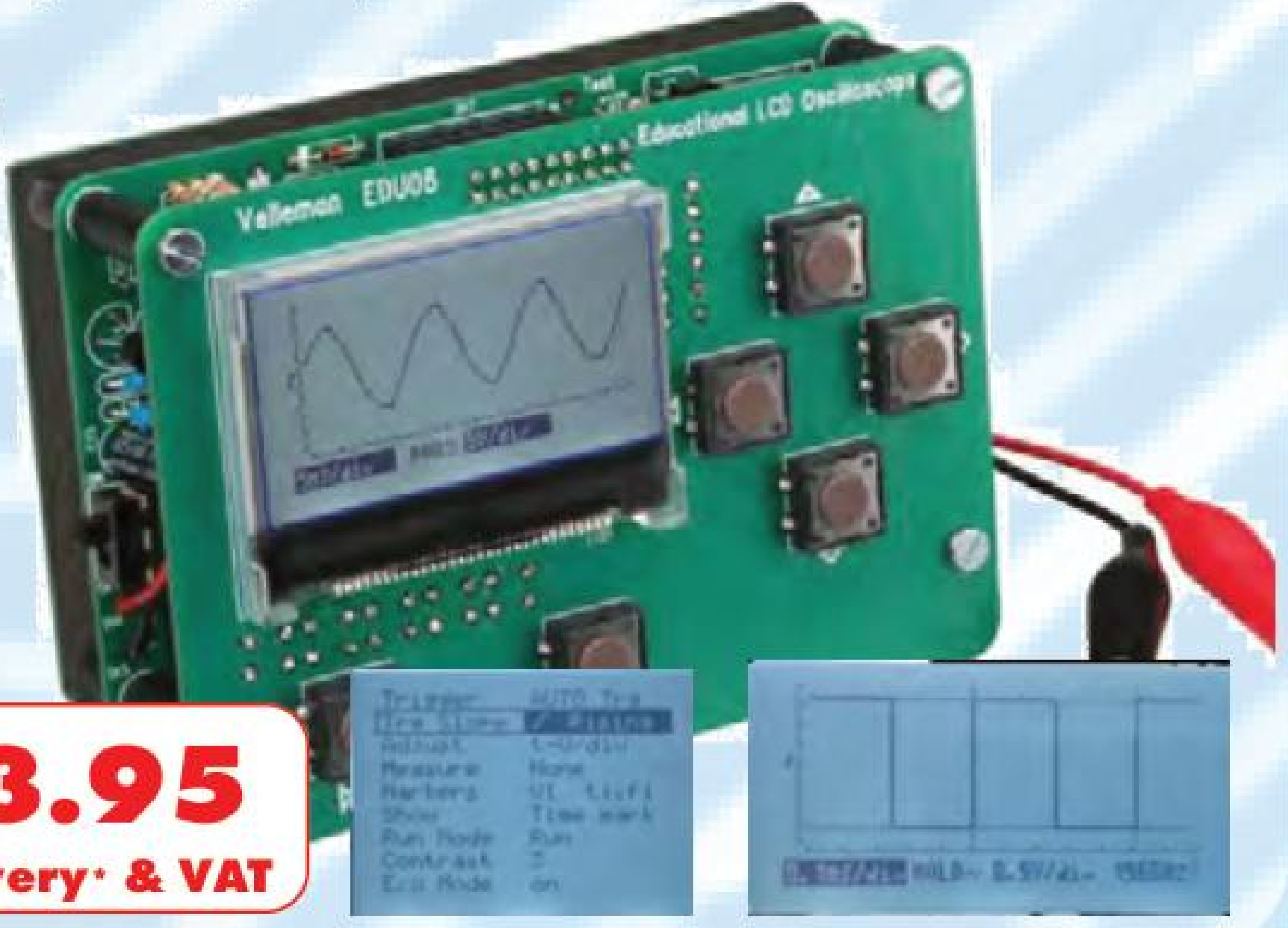

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Gravity light

Editors receive a lot of press releases via email, and almost all of them end up in the round folder as soon as they are opened. Recently, however, I was sent a genuinely interesting letter asking me to highlight a crowdfunding campaign: **https://www.indiegogo.com/projects/gravitylight-made-in-africa#/story**

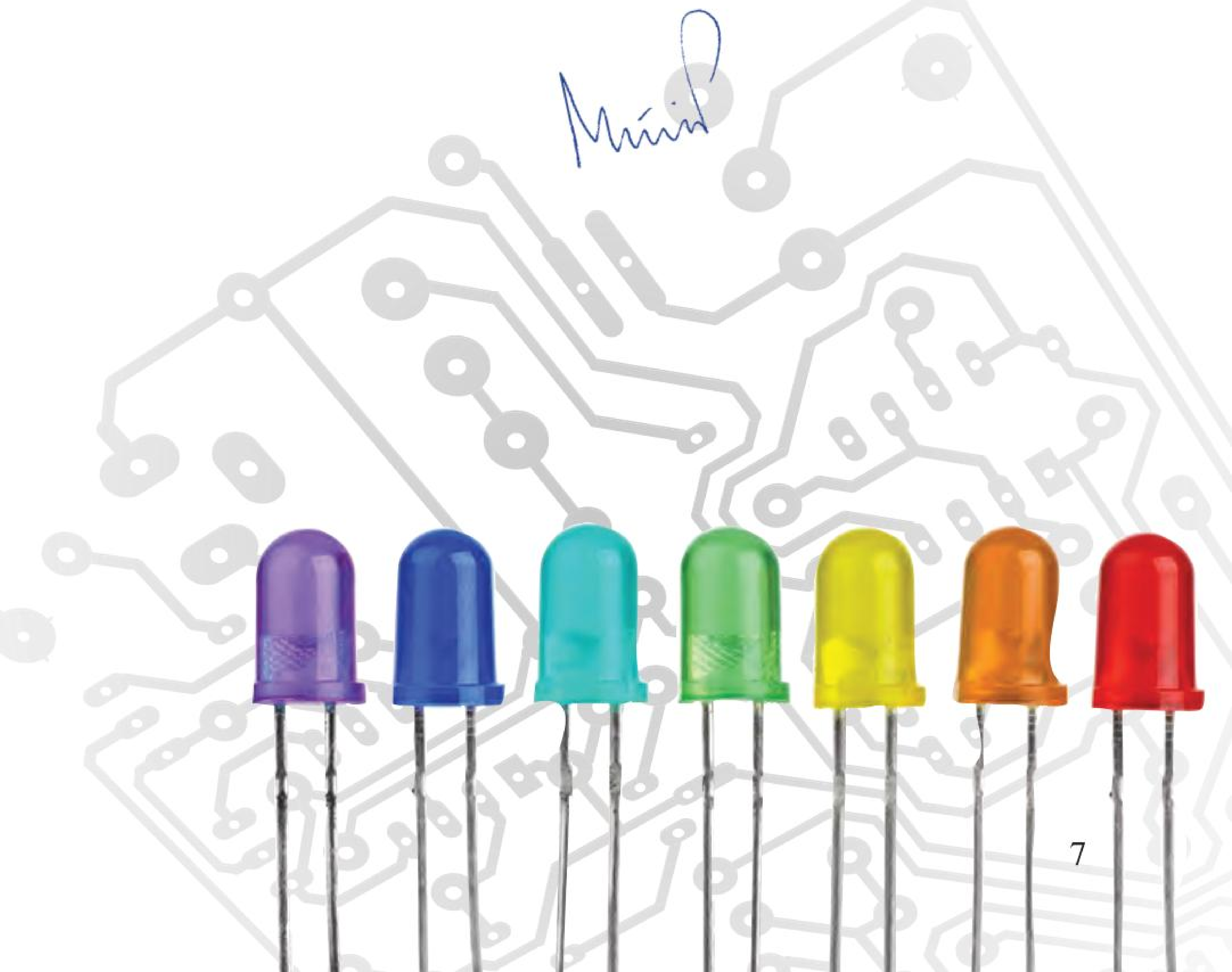
We tend to take our electricity-based lifestyle and all its accompanying benefits – including our fascinating hobby – for granted. But just imagine for a moment that you don't have an iPhone, PC or Hi-Fi. In fact, imagine you don't even have electricity – that is still an everyday reality for one in five people (that's 1.3 billion humans, well into the 21st century). No electricity means no electric light, so people frequently have to rely on dangerous and polluting kerosene lamps for domestic illumination.

One answer to this enforced off-grid problem is the 'GravityLight', which provides a cheap and simple electric light. The principle is straightforward – a simple DC generator is mechanically driven by a slowly falling bag of sand/rocks. The electrical output is used to power a high-efficiency white LED-based lamp. True, this is no spotlight, but positioned carefully, an LED light could provide enough low-cost, fume-free light to enable reading, work, or for children to do their homework.

In the latest version, a 6ft/2m drop provides roughly 20 minutes of light. When the bag hits the ground it is simply a matter of pulling it up and power starts to flow again. (More tech specs are available at the campaign's website: **http://gravitylight.org/tech-specs**)

And it's not just about light, the GravityLight also has a DC jack where other devices, such as a radio, can be attached.

It's a nice idea, and although it can't solve everyone's lighting problems, it could make a real difference to a lot of people without access to mains electricity. I hope you will visit the website and maybe support the campaign.



NEWS

A roundup of the latest Everyday News from the world of electronics

IFA Global Press Conference – report by Barry Fox

Germany's IFA (*Internationale Funkausstellung* – International Radio Exhibition) and America's CES (Consumer Electronics Show) both want to be seen as the biggest and best consumer electronics exhibition. Every spring, the IFA organisers pick a sunny European city and fly in several hundred journalists from around the world for a Global Press Conference (GPC) to promote IFA in Berlin in September, against CES in Las Vegas in January.

Windows 10 launch

The big news at this year's GPC (in Malta) was that Microsoft would be at the Berlin consumer show, promoting the new Windows 10 operating system, which is due for launch this summer. Microsoft sees Windows 10 (to replace Windows 8, with no intermediary Windows 9) as the bedrock for future home, mobile and business electronics.

Bryan Biniak, General Manager, Developer Experiences, Microsoft, was parachuted in for a 'Special Power Session'. He was allocated twice the time of all other speakers – and, to the audience's frustration – showed a video on surfing, before assuring that Microsoft is now seen as 'cool' and 'focussing on the consumer'.

Microsoft has never apologised for Windows 8, so I suggested that it might be useful if he asked for a show of hands on how many of the hundred or more press present 'liked or wanted Windows 8', Biniak agreed but his estimated percentages (60% tried, 30% used and 'less' liked) were generally thought to be a wildly over-optimistic denial of the evidence. Only two or perhaps three hands went up for liking Windows 8.

'Microsoft is now a very different place' Biniak then assured. 'People in the company are listening and acknowledging the success, actually lack of success, of Windows 8. It's a top priority to make Windows 10 successful.'

Asked at the next day's plenary session whether Microsoft's presence at the GPC meant that Microsoft would be part of the September show, Jens Heithecker, IFA's Executive Director, admitted it was the one question he had hoped he would not be asked.

Yes, no, maybe...

After explaining that he had met Bryan Biniak that morning before he flew back to the US for the Microsoft Developers conference in San Francisco and that 'Yes, Microsoft will exhibit, will be (an) exhibitor, at our show, this I can say today'. Heithecker then seemed to regret what he had said and retreated into mumbling 'it's enough for today'. When asked if that was a 'yes' or 'no', Heithecker replied 'it's a clear maybe'.

Philips blue-light remedy

At another power briefing, Bernd Laudahn, from Philips announced a new cure for back pain. The patient wears a pad which beams blue light on the back of the body. This 'acts on' the patient's blood, apparently to stimulate the natural production of nitric oxide and dilate the blood vessels, with consequent reduction in painful symptoms.

Green fridges and over-engineered knobs

Yannick Fierling, CEO Haier Europe, announced a new wine cellar cabinet which uses a credit-card-size solid-state cooling device, probably exploiting the well-known but inefficient Peltier effect, to replace the conventional bulky compressor. As only water and carbon dioxide are needed, the design is greener. 'We are working towards a solid-state refrigerator' he said.

Christian Struck, Brand Director Grundig Germany and Murat Sahin, CEO Grundig Multimedia BV and Beko Germany Regional Director Northern Europe, tracked a timeline of '70 years of uniqueness' from Grundig – leading up to a curved UHD TV and new teamaker. Curiously the timeline made no mention of the company's financial problems in 2003 and progressive takeover by Turkey's Beko.

Grundig's latest idea is to replace the knobs on a kitchen cooker with a complicated and expensive overhead video projection system that beams images of knobs onto a kitchen worktop. Why this is a good thing to do was never explained.

4k love

Paul Gray, Principal Analyst, IHS-DisplaySearch, confirmed previous predictions on 4k. Despite lack of standardisation, 4k sales are 'surging' at 550% year on year.

'It's an unmitigated success' said Gray, 'by 2018 all 50-inch+ TVs will be 3840 × 2160'.

'Pixels are like love – you just can't get enough'.

'But some viewers have reported discomfort with High Dynamic Range screens. You know how some TV commercials have very loud sound; well imagine what it will be like if soap powder advertisers use HDR to show how white they wash. You will have to put on sunglasses. It will be painful to watch'.

Gray also gave his warning take on watching streamed 4k UHD. 'People click on the 4k option but because of bandwidth limitations and contention (too many people sharing the same connection) they are not really watching 4k most of the time.'

IBM steps towards first practical quantum computer

IBM scientists have unveiled two critical advances towards the realisation of a practical quantum computer. For the first time, they showed the ability to detect and measure both kinds of quantum errors simultaneously, as well as demonstrating a new, square quantum bit circuit design that is the only physical architecture that could successfully scale to larger dimensions.

With Moore's Law expected to run out of steam, quantum computing will be among the inventions that could usher in a new era of innovation across industries. Quantum computers promise to open up new capabilities in the fields of optimisation and simulation simply not possible using today's computers. If a quantum computer could be built with just 50 quantum bits (qubits), no combination of today's TOP500 supercomputers could successfully outperform it.

The IBM breakthroughs show, for the first time, the ability to detect and measure the two types of quantum errors (bit-flip and phase-flip) that will occur in any real quantum computer. Until now, it was only possible to address one type of quantum error or the other, but never both at the same time. This is a necessary step toward quantum error correction, which is a critical requirement for building a practical and reliable large-scale quantum computer.

The most basic piece of information that a typical computer understands is a bit. Much like a beam of light that can be switched on or off, a bit can have only one of two values: '1' or '0'. However, a quantum bit (qubit) can hold a value of 1 or 0 as well as both values at the same time, described as superposition and simply denoted as '0+1'. The sign of this superposition is important because both states 0 and 1 have a phase relationship to each other. This superposition property is what allows quantum computers to choose the correct solution amongst millions of possibilities in a time much faster than a conventional computer.

Quantum information is important because it will help solve a class of problems that are unsolvable today, opening up a new realm of applications. Target problems include analysing 'big data', designing better drugs and new materials, machine learning and cryptography.

Future plans for Bletchley Park

On the 70th anniversary of VE Day (8 May), the Bletchley Park Trust announced its future plans for Bletchley Park working towards the goal of consolidating Bletchley Park as a world-class heritage site, museum and education centre for the ever-growing numbers of visitors, and as a permanent tribute to the men and women who worked there during WW2.

Exhibition and gallery space is to be expanded, a state-of-the-art education facility to inspire mathematicians and scientists of the future will be created, along with a modern archive to house Bletchley Park's unique, history-changing collection. All of this will result in Bletchley Park and its stories being made more accessible to visitors, scholars and researchers around the world.

Hobbyist soldering station from Allendale

Allendale has launched the Aoyue 469 – a low-cost soldering station perfect for hobbyists performing basic through-hole work, all the way up to larger SMD electronic repairs.

The 469 comes from Aoyue, the manufacturer of quality soldering products for both amateur and industry professionals. Despite its small-footprint, the station includes a handy solder reel holder and spring-type iron stand with cleaning sponge. The iron's handle is rubberised for superior grip.

It has an eight-position dial for varying iron temperature between 300 and 480°C with a fast acting PTC ceramic heater.

Tips are easily replaceable and compatible with any of Aoyue's large selection 'T' type product range.

Rated at 60W, the unit has sufficient power to melt through large joints but enough heat control to not ruin the board by getting too hot or make cold joints, if used correctly.

Further detailas are available at: **www.pcb-soldering.co.uk**

Smart streetlights...

Philips has announced that Los Angeles will become the first city in the world to control its street lighting through a new Philips management system that uses mobile and cloud-based technologies.

With the 'CityTouch' connected lighting management system, the LA Bureau of Street Lighting can remotely control lighting fixtures, as well as monitor energy use and the status of each light. Using mobile chip technology embedded into each fixture, the streetlights are able to identify themselves and network instantly. The entire system can be securely controlled and managed remotely through any web browser.

While CityTouch is already in use in 31 countries, the LA solution is the first connecting directly to each light point using a 'connector node', which can connect streetlights from any manufacturer. The 'plug & play' connector nodes plug into a standard socket, and connect automatically to the software when installed.

... 'Smartest city'

Last November, Tel Aviv won coveted international recognition as the 'World's Smartest City' at the Smart City Expo World Congress in Barcelona. Central to this success was the city's free Wi-Fi system, launched by the municipality 18 months ago. It includes 180 free hot spots covering 3.7 million square meters and encompassing the entire city. The city's beaches, boulevards, coffee shops, bars, parks, and startup hubs are all covered by free Wi-Fi zones.

According to the latest data from 2014, more than 50% of web entrances were made by tourists visiting Tel Aviv, with 85% of entrances made using smart phones. The data show that English was the most popular language.

Hila Oren, CEO of Tel Aviv Global said: 'Today, access to free Wi-Fi is a basic service – just like it's a City's job to connect people to water and electricity – it is also our job to connect people to the web – free Wi-Fi is a new aspect of city-making.'

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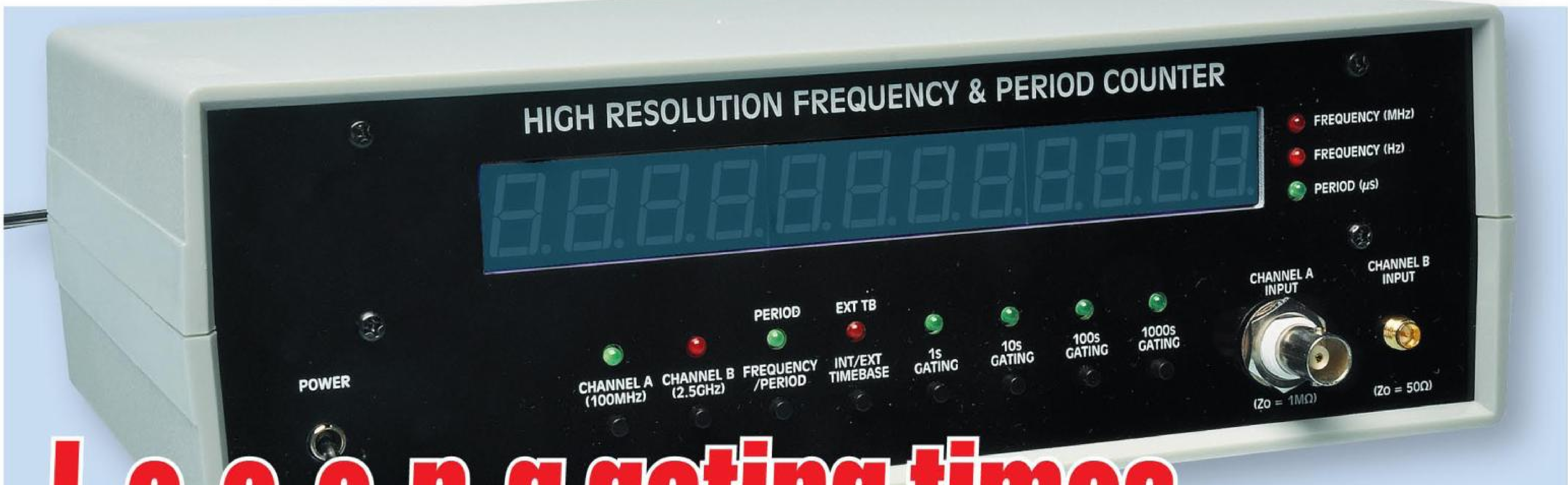


L-o-o-o-n-g gating times for the 12-Digit High-Resolution Counter

By JIM ROWE

This add-on PCB module enables higher resolution measurements with the *12-Digit Frequency/Period Counter* described in the January 2014 and February 2014 issues of *EPE*. It adds an additional decade divider for the external timebase input to allow measurements using a gating time of 10,000 seconds (nearly three hours) and includes front-panel LEDs for gating indication.

DURING OUR RECENT work in calibrating an ex-telecoms rubidium frequency standard (*EPE*, April 2015), it became apparent that it was possible to improve the *12-Digit High Resolution Counter* to make it better for this type of very high resolution frequency measurement. This would involve a small module which could be housed inside the counter's case. The end result provides three separate improvements, as outlined below.

One of the functions I wasn't able to provide on the original *12-Digit High Resolution Counter* was any indication of when the counter's gate is open and counting is under way. This doesn't matter much when you're making measurements at short gating times – one or ten seconds – because each new reading follows the last in relatively short order. But it's a drawback when using longer gating times for higher resolution frequency measurements.

For example, if you want to measure with a resolution of 1mHz (0.001Hz), each measurement involves a gating time of 1000 seconds and there's also a gap of 1000 seconds between measurements, because of the way the counter works. Without any indication of when the gate is actually open and counting is taking place, it's not possible to tell whether it's counting or 'waiting between counts'.

So one of the improvements provided by the new add-on module is to provide an indication of when the counter's gate is open and counting is under way. It does this with a bi-colour LED, which is red when the gate is open for odd counts and green when the gate is open for alternate even counts. Because it doesn't light at all during the gaps between counts, this makes it quite easy to tell at a glance what the counter's status is at any particular time.

But what if you're over the other side of the room, or perhaps in another room – so you can't be glancing over at the counter all the time? To solve this, the module includes a simple beeper circuit, which operates a piezo buzzer for a short time at the start of each new counting period. So all you need to do is keep an ear out for the beep, to let you know when a new count has begun. Then you can go over to the counter and record the previous count (which continues to be displayed during the new count).

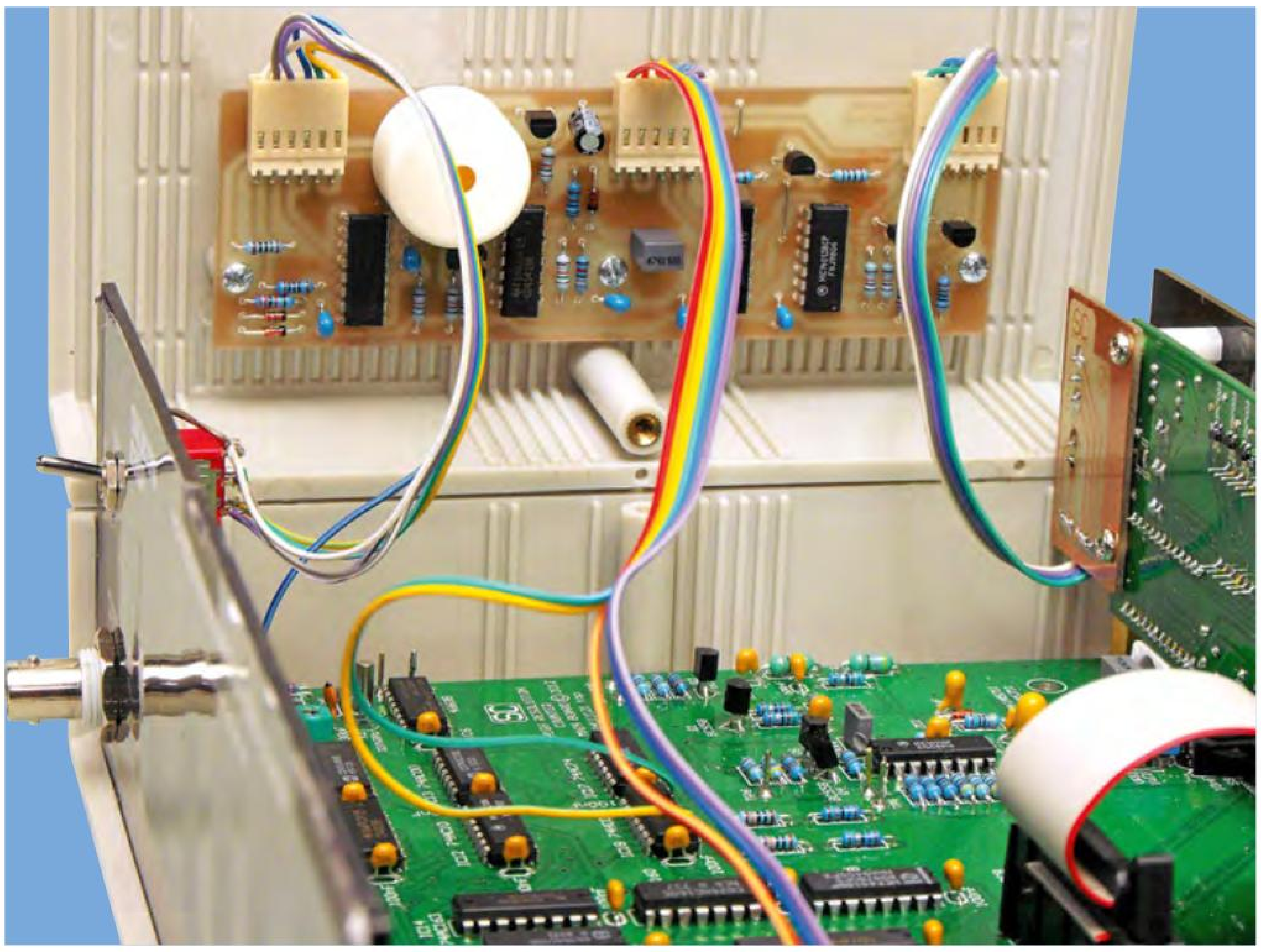
The circuit of the add-on module has been arranged so that the beeper is only activated when the counter is set for gating times of 100s or more. For the shorter gating times, it's disabled.

The beeper circuit is also link-programmable with respect to the actual beep duration. There's a choice of four different beep durations: 0.5 seconds, 2 seconds, 16 seconds or 128 seconds. So you can easily select the duration that's most suitable for your application.

The third improvement provided by the new module enables the counter to make *really* high resolution measurements. It's an additional synchronous decade divider for the counter's external timebase input, so that the maximum gating time/counting period can be extended to 10,000 seconds – allowing you to make frequency measurements with a resolution of 100μHz (100 microhertz or 10^{-4}Hz).

But there's a price to pay for making this type of measurement with the counter: each count will take 2 hours and 47 minutes, with a gap of the same duration between counts. So you'll need to be patient, but at least the indicator LED and beeper will let you get on with other things!

Note that the additional timebase divider can be switched out of circuit when it's not needed and another LED indicates when the additional divider is being used. This LED will also remind you to 'bump up' the decimal point in the counter's display, because the counter itself has no way of knowing that the additional divider is in use.



The main add-on logic module is mounted on the lid of the counter's case, while the smaller add-on LED board is attached to one end of the counter's display PCB. An extra switch is also mounted on the rear panel.

Circuit details

The full circuit for the new add-on module is shown in Fig.1. The circuitry for the 'gate open' indication is at the top, the 'beep at the start of each count' function is in the centre and the additional timebase divider circuitry is at the bottom.

The 'gate open' indication circuitry involves gate IC1b, flip-flop IC2a and transistors Q1, Q2 and Q3. IC1b is used as an inverting buffer, which takes a $\overline{\text{GATE OPEN}}$ signal derived from pin 2 of IC18a on the counter's main PCB and inverts it to provide an active high GATE OPEN signal with a positive-going leading edge. This leading edge is then used to toggle flip-flop IC2a, which therefore changes state at the start of each new count.

The flip-flop's two outputs (Q and $\overline{Q}$) are then used to control transistors Q2 and Q3, so only one of these is able to conduct at any time to allow current to flow through either LED1a or LED1b. This depends on whether the counter is performing an odd count or an even count, although these labels are purely arbitrary.

Whether either of the two LEDs is able to conduct current doesn't just depend on transistors Q2 and Q3, however; because neither LED can pass current unless transistor Q1 is also conducting. Q1 is only able to conduct current when it is provided with forward base current via the 22kΩ series resistor connected to pin 4 of IC1b.

So Q1 only conducts when the GATE OPEN signal on pin 4 of IC1b is high (ie, during counting).

Hence LED1a lights only during odd counting periods and LED1b is on only during even counting periods. In the gaps between counting periods, both LEDs remain dark.

Gating beeper circuit

The beeper section involves gates IC1a, IC1c and IC1d, together with timer IC3 and transistor Q4 to switch the piezo buzzer on and off.

The input gating circuitry may look a little strange, but it's really quite straightforward. IC1a is being used as another inverter, to derive a $\overline{\text{GATE OPEN}}$ signal from the signal at pin 4 of IC1b. This is then fed to pin 13 of IC1d, used here as a negative input logic AND gate.

We don't want the beeper to function when the counter is being used with the shorter gating periods, so the second input of IC1d (pin 12) is connected to IC1c's output pin (pin 10), while IC1c's inputs are connected to two pins of IC23 on the main counter PCB: pin 2, which carries the 100s gating signal (H = 100s gating) and pin 6, which carries the 1000s gating signal (H = 1000s gating).

Since IC1c is a NOR gate, this means that its pin 10 output will only switch low when the counter is set for either 100s or 1000s gating. Accordingly, pin 12 of IC1d will only be taken low for these gating times also, and will be kept high for the shorter gating times. So even when pin 13 of IC1d drops low during GATE OPEN periods, IC1d's pin 11 output will not be able to switch high unless the counter is set for either 100s or 1000s gating.

The output from pin 11 of IC1d is coupled to the MRST input (pin 6) of timer chip IC3 via a differentiator circuit using a 470nF capacitor and 10kΩ resistor. This is done so that IC3 only receives a short triggering pulse, derived from the leading edge of the gated positive-going signal from IC1d. I'll explain the reason for this shortly.

IC3 is a 4541B programmable digital CMOS counter/timer, used here to time the duration of our 'start of a new count' beeper. It's triggered via MRST input pin 6, while its output at pin 8 is used to control the piezo buzzer via transistor Q4. The duration of the output pulse (and therefore the length of the beep) is determined by the timing components connected to pins 1, 2

Parts List

- 1 PCB, available from the *EPE PCB Service,* code 04106141, 169 × 45mm (cut into two boards, 137 × 45mm and 30.5 × 45mm)
- 3 6-pin PCB-mount right-angle polarised locking headers, 0.1-inch spacing
- 3 6-pin polarised locking plug sockets, 0.1-inch spacing
- 2 2-pin SIL headers (or 1 × 4-pin DIL header) for LK1 and LK2)
- 2 2-pin jumper shunts
- 1 piezo buzzer, 24mm diameter, PCB mounting
- 1 DPDT panel-mount mini toggle switch
- 1 1m-length of 6-conductor rainbow ribbon cable
- 3 6G × 6mm self-tapping screws
- 2 M3 × 9mm machine screws
- 2 M3 flat washers

Semiconductors
- 1 4001B quad CMOS NOR gate (IC1)
- 1 4013B dual D-type flipflop (IC2)
- 1 4541B programmable CMOS timer (IC3)
- 1 4017B Johnson decade counter/divider (IC4)
- 2 PN100 NPN transistors (Q1,Q4)
- 2 PN200 PNP transistors (Q2,Q3)
- 1 5mm 3-pin common-cathode red/green bicolour LED (LED1)
- 1 3mm blue LED, waterclear (LED2)
- 3 1N4148 silicon diodes (D1-D3)

Capacitors
- 1 10µF 16V RB electrolytic
- 1 470nF MKT or MMC
- 6 100nF MMC (multilayer monolithic ceramic)

Resistors (0.25W 1%)
- 1 33kΩ
- 4 22kΩ
- 2 15kΩ
- 6 10kΩ
- 1 2.2kΩ
- 2 1kΩ
- 1 470Ω
- 1 100Ω

and 3, which set the frequency of the 4541B's internal clock oscillator and also by links LK1 and LK2, which program the 4541B in terms of its timing count setting. As you can see from the small table at centre left of Fig.1, the link combinations provide a choice of four beep durations: from half a second up to 128 seconds.

But why did we have to provide a short triggering pulse for IC3 – why couldn't we simply use the logic output signal from IC1d directly? That's because IC3 only provides its 'end of timing count' output pulse from pin 8 if the input triggering pulse supplied to pin 6 has ended. And in this circuit, the output signal from IC1d can of course stay at the high logic level for as long as 100s or 1000s (or even 10,000s), which would prevent IC3 from ever activating the beeper.

So, by using the simple differentiator shown, we derive a relatively short trigger pulse from the rising edge of the output signal from IC1d, ensuring that the triggering signal at pin 6 of IC3 has dropped back to zero in no more than about 100ms. This allows correct beeper operation, even with a beep duration of only 0.5 seconds.

By the way, diode D3 is provided simply to ensure that any negative pulse appearing at input pin 6 of IC3 when the output of IC1d does drop back to zero (when the counter's gate finally closes) is limited to an amplitude of –0.6V.

Additional divider stage

Now let's look at the circuitry at the bottom of Fig.1, which provides the additional 'divide-by-10' function to extend the counting duration when using an external timebase, eg, the 1Hz pulses from a GPS receiver or a rubidium time and frequency standard.

This uses a 4017B Johnson-type synchronous CMOS decade counter (IC4). Its CP0 input (pin 14) is connected directly to CON3 at the rear of the main counter PCB, which is disconnected from the original external timebase input by removing the 1kΩ series resistor just to the front of CON3. Diodes D1 and D2, together with the 100Ω and 22kΩ resistors, are used to protect the input of IC4 from possible over-voltage damage.

This additional timebase divider is always fed with the external timebase signal from CON3. However, whether or not its output is fed to the external timebase input of the counter is controlled by added switch S1, which is fitted to the counter's rear panel. This is a double-pole switch, with its 'a' section used to select either the raw external timebase signal from CON3 or alternatively, the pin 12 output of IC4.

S1a's common terminal is connected back to the external timebase input of the counter via a 1kΩ series resistor, which replaces the one that's removed to tap into the signal from CON3.

S1b is simply used to switch LED2 in or out of circuit, so that this LED only glows when S1a has been set to make use of the additional timebase divider.

One last point: the 100nF capacitor and 10kΩ resistor connected to pin 15 of IC4 are simply there to deliver a short reset pulse to this IC when power is first applied to the counter, so that IC4 starts off 'on the right foot'.

Construction

As shown in Fig.2 and the photos, virtually all the components used in the add-on module are fitted onto two small PCBs, which are cut apart from a single board measuring 169 × 45mm and available from *EPE PCB Service*, coded 04106141. The larger PCB (coded 04106141a) carries most of the components and circuitry, and mounts up inside the righthand end of the counter's lid.

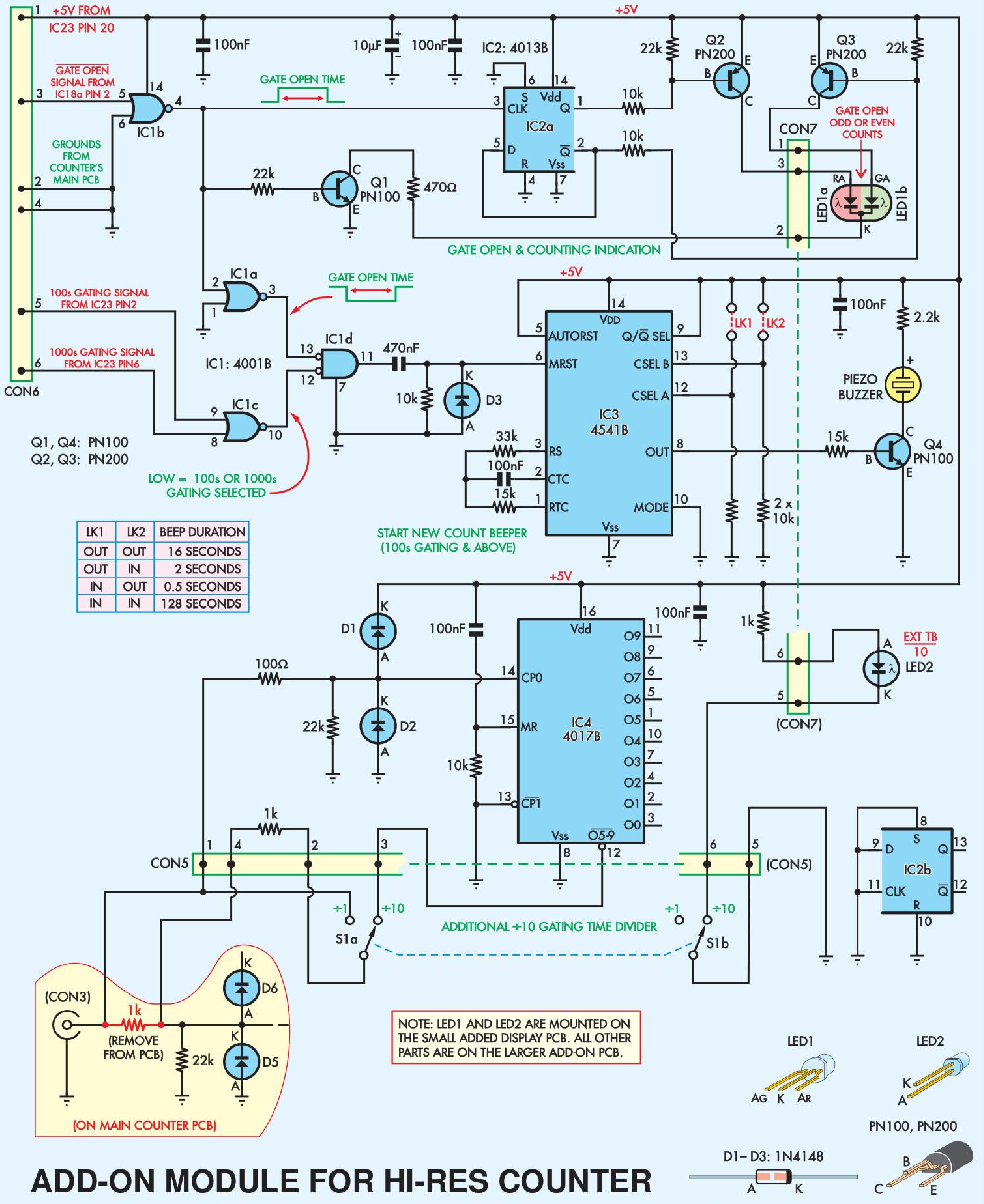
The smaller PCB (coded 04106141b) carries only the two extra LEDs and is mounted at the righthand end of the counter's display PCB, behind the front panel and with the extra LEDs just protruding through two additional holes in the panel.

Three ribbon cables are used to make the connections. These go between the two add-on PCBs, between the larger add-on PCB and the main counter PCB, and to added switch S1 and the external timebase input circuitry (CON3). This should all be fairly clear from the overlay diagram of Fig.2 and also the internal photos.

Cut the two boards apart and smooth their cut edges with a small file before you add any of the components. You can then begin the assembly of the larger board by installing the two wire links, followed by the resistors, diodes, capacitors, transistors and ICs.

The three 6-pin 90° header plugs and the two 2-pin SIL headers for LK1 and LK2 can then go in. The piezo buzzer can be left until last, as it's relatively large and makes it hard to access some of the other components once it's in place.

Next, you can fit the two LEDs to the smaller PCB, both with their 'flat' sides (cathodes) downwards as shown in Fig.2. Leave their leads about 14mm long above the top surface of the PCB, as this will be about the right length for the LEDs to protrude slightly through the front panel when the board is mounted in position.


+5V FROM IC23 PIN 20
+5V
100nF
10µF
100nF
IC2: 4013B
22k
Q2 PN200
Q3 PN200
22k
GATE OPEN SIGNAL FROM IC18a PIN 2
GATE OPEN TIME
IC1b
S Vdd
CLK Q
IC2a
D Q̅
R Vss
10k
10k
GATE OPEN ODD OR EVEN COUNTS
CON7
GROUNDS FROM COUNTER'S MAIN PCB
22k
Q1 PN100
470Ω
RA GA
LED1a LED1b
GATE OPEN & COUNTING INDICATION
IC1a
GATE OPEN TIME
+5V
100s GATING SIGNAL FROM IC23 PIN2
1000s GATING SIGNAL FROM IC23 PIN6
IC1d
470nF
IC1: 4001B
CON6
10k
D3
VDD
AUTORST Q/Q̅ SEL
MRST CSEL B
CSEL A
IC3 4541B
RS OUT
CTC
RTC MODE
Vss
33k
100nF
15k
LK1 LK2
100nF
2.2k
PIEZO BUZZER
15k
Q4 PN100
2 x 10k
IC1c
Q1, Q4: PN100
Q2, Q3: PN200
LOW = 100s OR 1000s GATING SELECTED
START NEW COUNT BEEPER (100s GATING & ABOVE)
+5V
D1
100nF
100nF
1k
Vdd
CP0
MR
IC4 4017B
CP̅1̅
Vss O̅5̅-̅9̅
O9 O8 O7 O6 O5 O4 O3 O2 O1 O0
100Ω
22k
D2
10k
1k
EXT TB 10
LED2
(CON7)
CON5
(CON5)
÷1 ÷10
S1a
÷1 ÷10
S1b
ADDITIONAL ÷10 GATING TIME DIVIDER
IC2b
S
D Q
CLK Q̅
R
(CON3)
1k (REMOVE FROM PCB)
22k
D6
D5
(ON MAIN COUNTER PCB)
LED1
AG K AR
LED2
K A
PN100, PN200
D1– D3: 1N4148
A K
B C E

LK1	LK2	BEEP DURATION
OUT	OUT	16 SECONDS
OUT	IN	2 SECONDS
IN	OUT	0.5 SECONDS
IN	IN	128 SECONDS

NOTE: LED1 AND LED2 ARE MOUNTED ON THE SMALL ADDED DISPLAY PCB. ALL OTHER PARTS ARE ON THE LARGER ADD-ON PCB.

ADD-ON MODULE FOR HI-RES COUNTER

Fig.1: the add-on module is based on four CMOS ICs (IC1-IC4). The 'gate open' indication circuitry is at the top, the 'beep at the start of each count' circuit is in the centre and the added timebase divider circuitry is at the bottom.

Once both PCBs have been fully assembled, the larger one can be fitted inside the upper half of the counter's case, at the righthand end. Note that it is mounted upside-down, with the copper side towards the case lid and the component side facing inwards. The PCB is held in place using three small 6mm-long self-tapping screws which

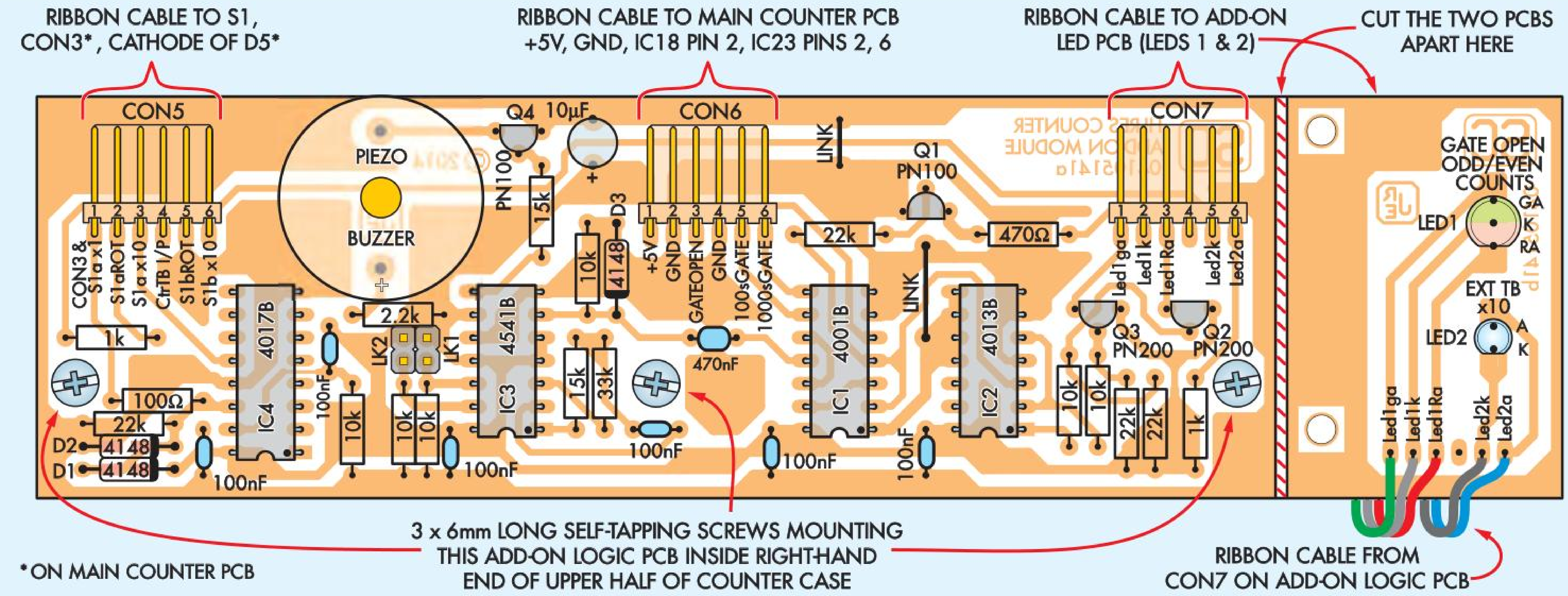

RIBBON CABLE TO S1, CON3*, CATHODE OF D5*
RIBBON CABLE TO MAIN COUNTER PCB +5V, GND, IC18 PIN 2, IC23 PINS 2, 6
RIBBON CABLE TO ADD-ON LED PCB (LEDS 1 & 2)
CUT THE TWO PCBS APART HERE
CON5
1 2 3 4 5 6
CON3 & S1a x1
S1aROT
S1a x10
CtrTB I/P
S1bROT
S1b x10
PIEZO
BUZZER
Q4
PN100
10µF
15k
10k
4148
D3
CON6
+5V
GND
GATEOPEN
GND
100sGATE
1000sGATE
LINK
Q1
PN100
22k
470Ω
CON7
Led1ga
Led1k
Led1Ra
Led2k
Led2a
GATE OPEN ODD/EVEN COUNTS
LED1
GA
K
RA
EXT TB x10
LED2
A
K
1k
4017B
IC4
100nF
2.2k
LK2
LK1
4541B
IC3
15k
33k
470nF
4001B
IC1
4013B
IC2
Q3
PN200
Q2
PN200
10k
22k
1k
100Ω
22k
D2
D1
4148
100nF
10k
3 x 6mm LONG SELF-TAPPING SCREWS MOUNTING THIS ADD-ON LOGIC PCB INSIDE RIGHT-HAND END OF UPPER HALF OF COUNTER CASE
*ON MAIN COUNTER PCB
RIBBON CABLE FROM CON7 ON ADD-ON LOGIC PCB

Fig.2: cut the PCB into two sections as indicated, before installing the parts on the two modules. Make sure that all polarised parts are correctly oriented and be careful not to get the ICs mixed up. The photo opposite right shows the completed add-on logic module mounted in place on the case lid.

mate with three of the small standoffs moulded inside the case lid at that end.

After that, you need to drill two additional holes in the counter's front panel (to allow the two extra LEDs to protrude and be visible) and also a single additional hole in the rear panel to accept toggle switch S1.

Fig.5 shows the size and location of these two additional holes in the front panel. Note that these line up horizontally with the uppermost and lowest of the three existing LED holes in the panel just to the right of the main display window, but are only 10mm in from the righthand end of the panel.

The single additional hole in the rear panel should have a diameter of 6.5mm to allow S1 to be fitted, but its exact location is not critical.

This should be located directly above CON3, about 55mm up from the bottom of the rear panel. This allows S1 to be activated quite easily by reaching over the case top.

The next step is to make up the three interconnecting ribbon cables. One of these (the one to connect from the centre connector to various points on the main counter PCB) should be about 300mm long, while the other two can be around 230mm long.

One of the two shorter cables (the one used to connect to the small LED display PCB) needs only five conductors rather than six.

To assemble each cable, bare all of their conductors for about 4mm at each end. Then you need to crimp and solder each conductor (at one end) to one of the pins of a 6-way polarised and locking header socket. That done, you can cut the pins from their carrier strip and push each one into the slots of the plastic socket moulding. Make sure that you push each clip fully home, ie, until its small barb clicks into the slot near the end. If you don't do this, the clips won't remain in position.

Make sure also that with the 5-wire shorter cable, you push the five clips into slots 1, 2, 3, 5 and 6 of the header socket. **Leave slot 4 empty, because the corresponding pin of CON7 (the connector with which this cable socket mates) isn't used.**

Once the header sockets have been attached to one end of each cable, you're then ready to connect the free ends of each cable to the designated points on either the small add-on display PCB, the counter's main PCB or the added toggle switch S1, on the rear panel.

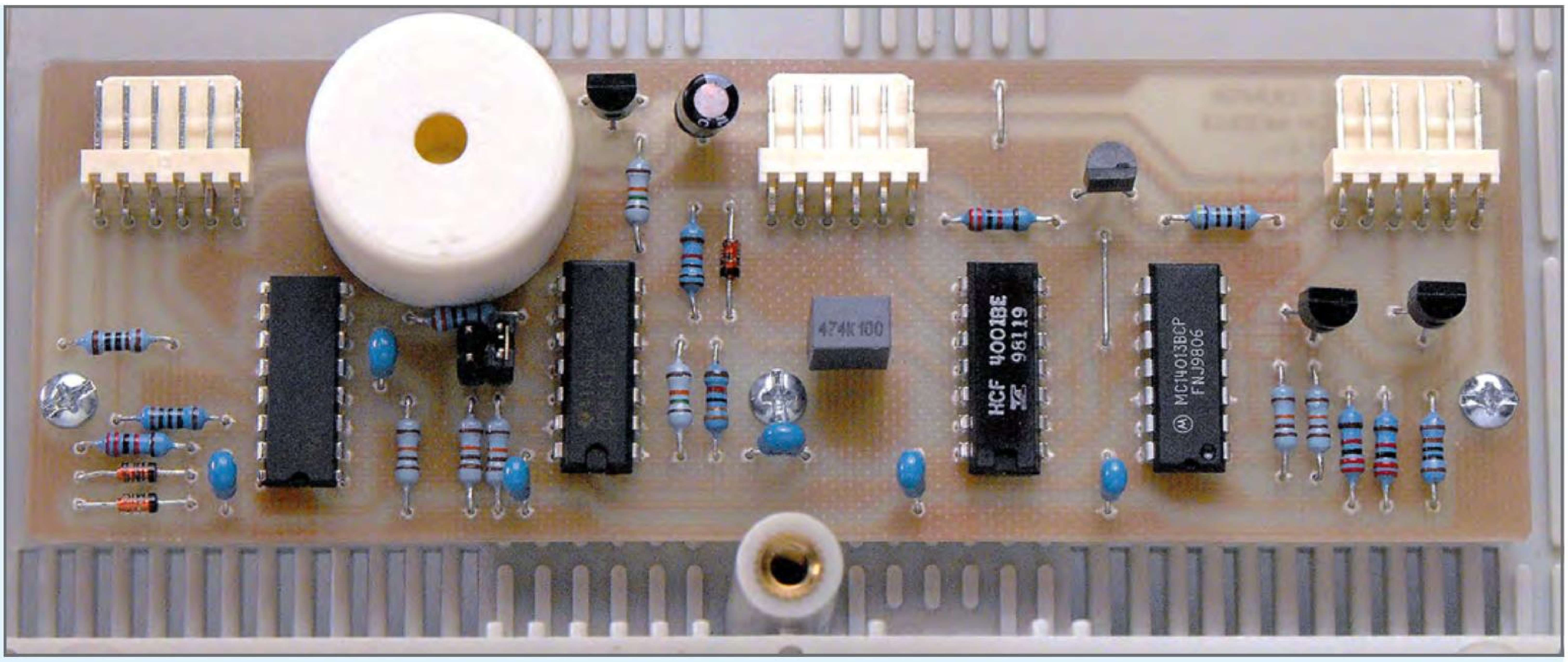
For example, the conductors of the short 5-way cable are connected to their matching holes along the bottom of the LED display PCB (04106141b), as shown at bottom right in Fig.2. Once all five have been soldered to their pads on the rear of the add-on LED PCB, this board can be fitted into the counter case.

Table 2: Capacitor Codes

470nF	0.47µF	470n	474
100nF	0.1µF	100n	104

Table 1: Resistor Colour Codes

☐	No.	Value	4-Band Code (1%)	5-Band Code (1%)
☐	1	33kΩ	orange orange orange brown	orange orange black red brown
☐	4	22kΩ	red red orange brown	red red black red brown
☐	2	15kΩ	brown green orange brown	brown green black red brown
☐	6	10kΩ	brown black orange brown	brown black black red brown
☐	1	2.2kΩ	red red red brown	red red black brown brown
☐	2	1kΩ	brown black red brown	brown black black brown brown
☐	1	470Ω	yellow violet brown brown	yellow violet black black brown
☐	1	100Ω	brown black brown brown	brown black black black brown


474K100
HCF 4001BE 98119
MC14013BCP FNJ9806

Mounting the LED board

As you can see from Fig.3 and one of the inside photos, the added LED display PCB is mounted just behind the counter's existing main display PCB, at its righthand end (as viewed from the front of the counter). This is done by removing the two existing M3 × 6mm screws attaching the main display PCB to the nylon spacers at that end, and then replacing them with two M3 × 9mm screws and M3 flat washers.

Each of these screws pass through a mounting hole of the add-on LED PCB (from the copper side), then through an M3 flat washer (acting as a thin spacer) before passing through the holes in the main display PCB and then into the nylon spacers as before. When both screws are tightened, both boards will then be mounted securely behind the front panel.

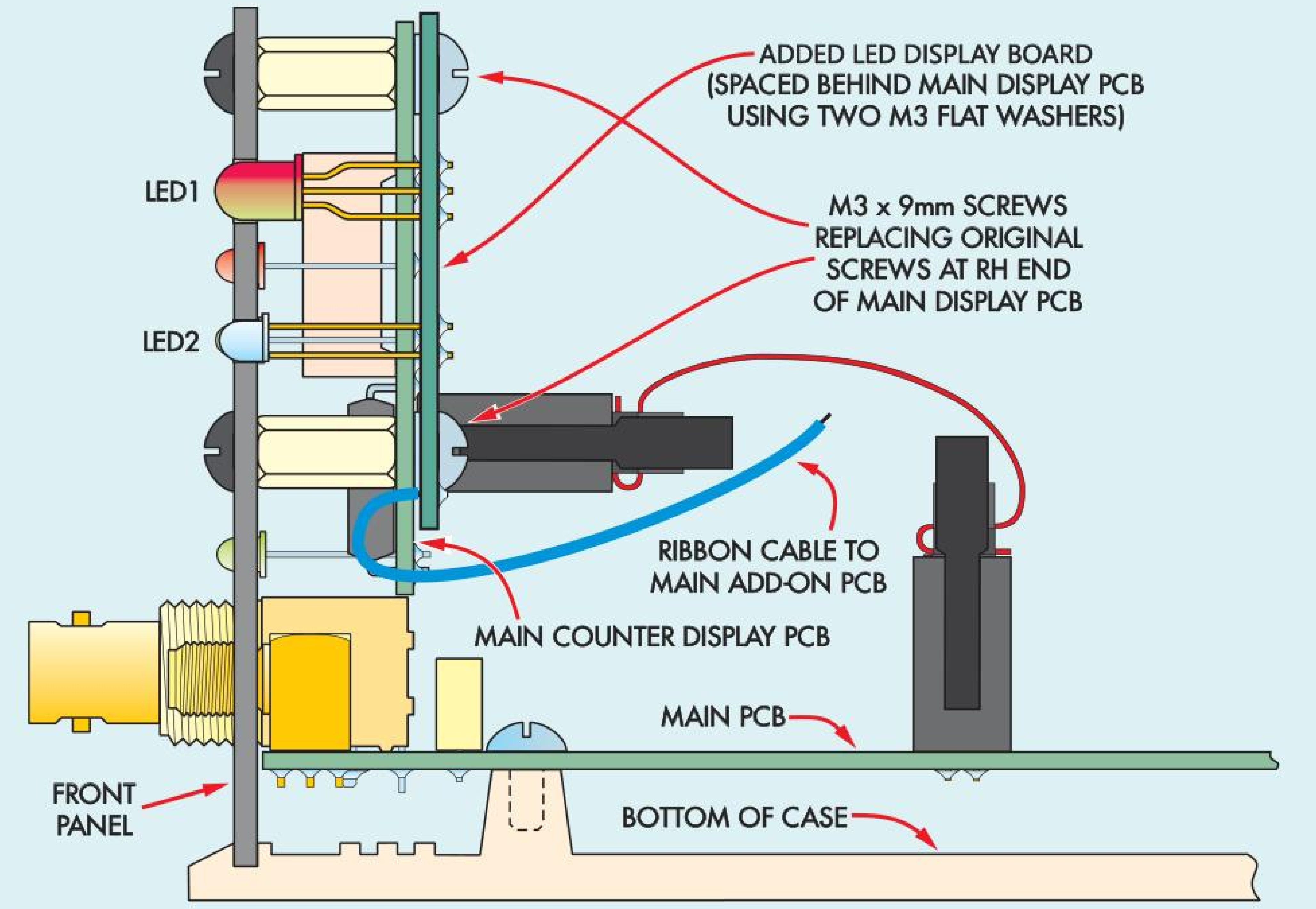

ADDED LED DISPLAY BOARD (SPACED BEHIND MAIN DISPLAY PCB USING TWO M3 FLAT WASHERS)
M3 x 9mm SCREWS REPLACING ORIGINAL SCREWS AT RH END OF MAIN DISPLAY PCB
LED1
LED2
RIBBON CABLE TO MAIN ADD-ON PCB
MAIN COUNTER DISPLAY PCB
MAIN PCB
FRONT PANEL
BOTTOM OF CASE

Fig.3: this cross-section diagram shows how the add-on LED display PCB is attached to the righthand end of the original display PCB (as viewed from the front) using two M3 flat washers plus two M3 × 9mm machine screws into the original nylon spacers.

Once the other shorter ribbon cable has been fitted with its 6-way header socket and clips, you can then solder the free ends of two of its conductors to the main counter PCB, just behind CON3 at the right rear and to the pads at each end of the position where the 1kΩ resistor was removed (see photo).

Basically, the conductor coming from pin 4 of CON5 (on the add-on logic PCB) connects to the pad on the left, while the conductor from pin 1 of CON5 connects to the pad on the right. **The latter also connects to the upper left lug of switch S1, although you may wish to make this second connection using another short length of hookup wire.**

The other four conductors of this ribbon cable connect to the other lugs of S1. The one from CON5 pin 2 goes to the centre lefthand lug, while the one from CON5 pin 3 goes to the lowest lug on the lefthand side.

Similarly, the one from CON5 pin 6 goes to the lowest lug on the righthand side of S1, while the one from CON5 pin 5 goes to the centre-right lug of switch S1 (the common terminal).

All that remains after the two shorter ribbon cables have been fitted is to do the same with the longest of the three cables. This is the one used to make the connections between CON6 of the add-on logic PCB to various points on the counter's main PCB. All of these points are pins on two of the ICs and it's quite easy to solder each lead to its corresponding pin using a fine-tipped soldering iron.

Here's how these conductors are wired. First, the wire from CON6 pin 1 goes to pin 20 of IC23, on the lefthand rear side of the main PCB. The wire from CON6 pin 2 then goes to pin 1 of the same IC, while the wires from CON6 pins 5 and 6 go to pins 6 and 2 of IC23, respectively.

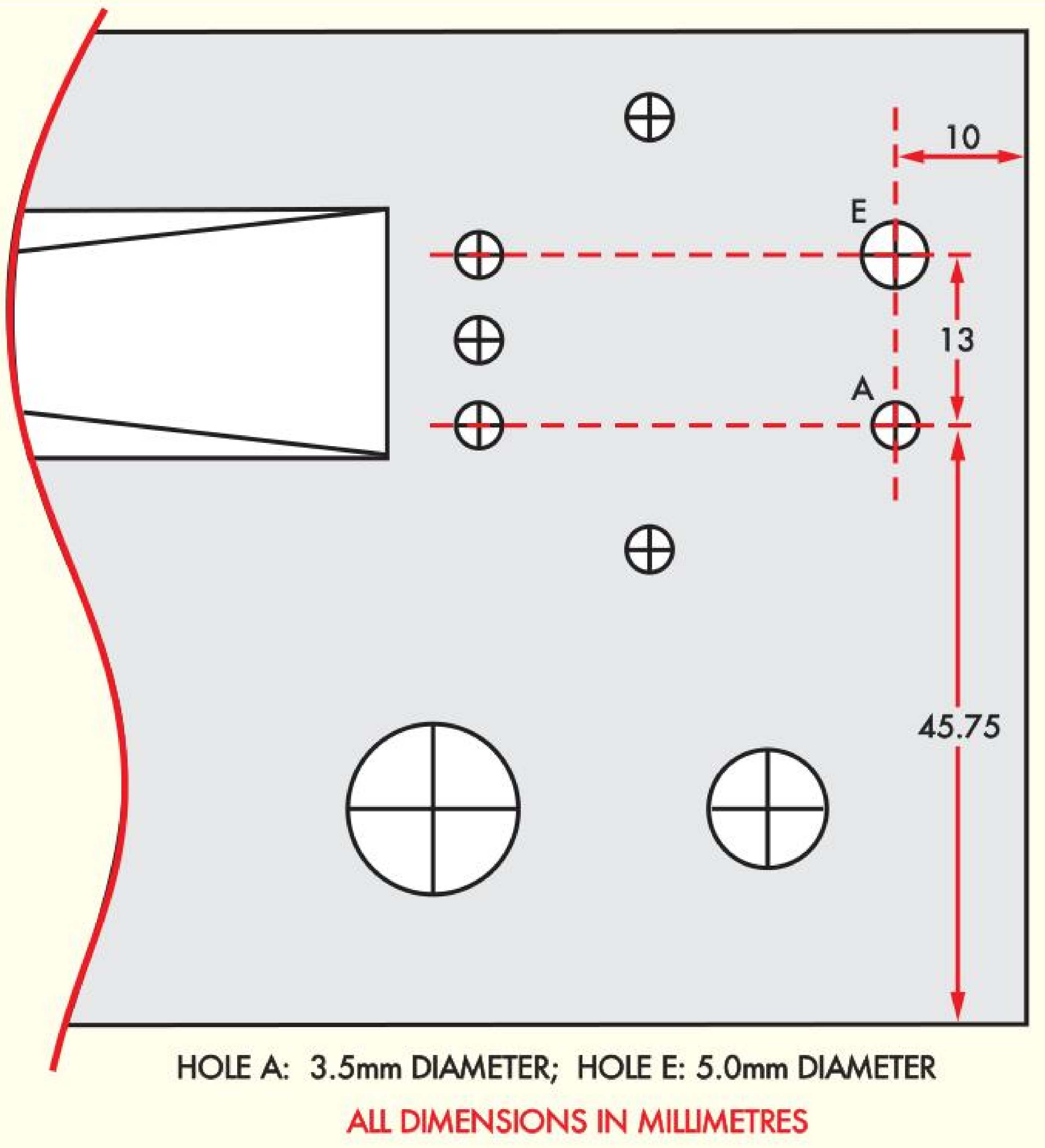
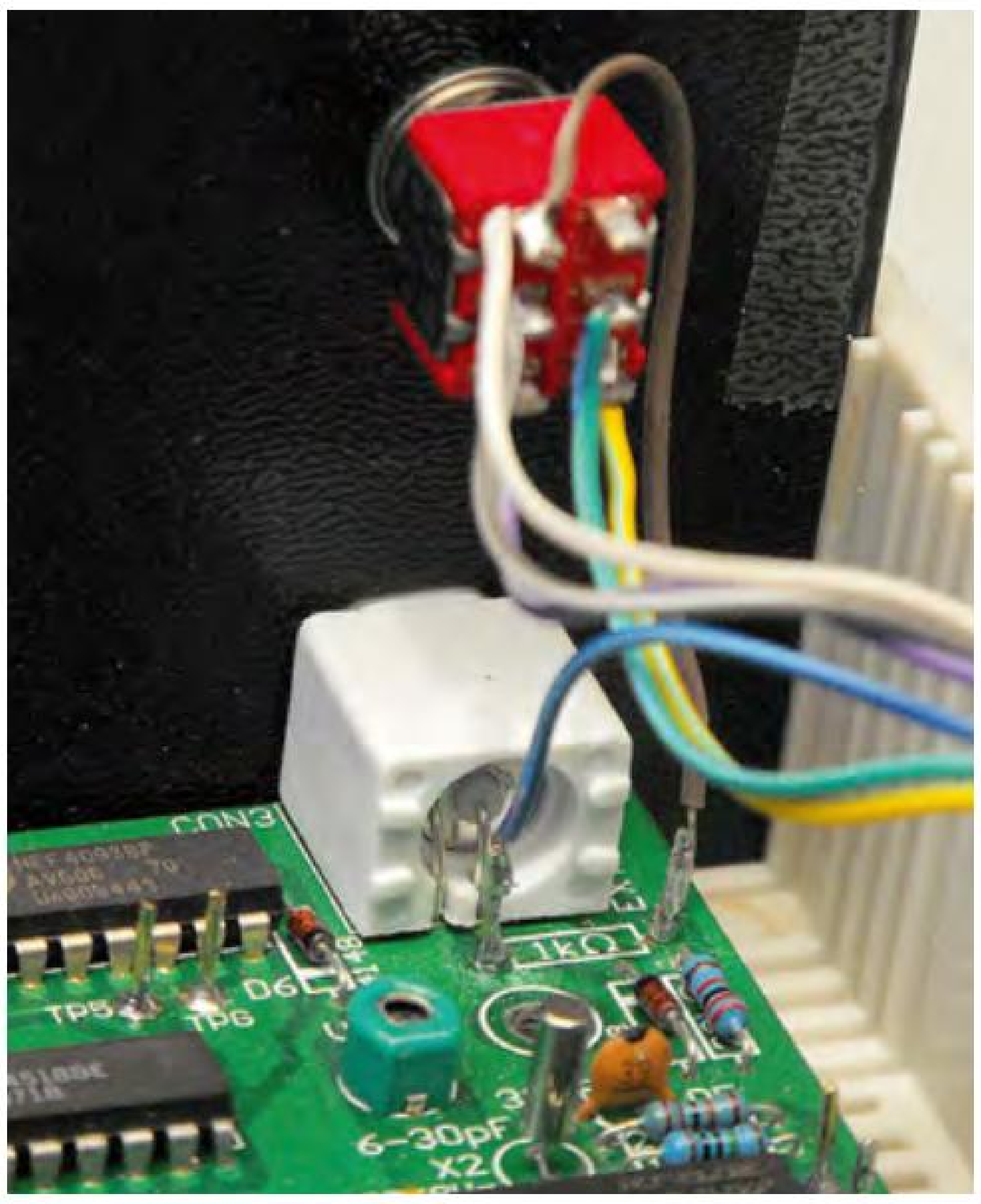

10
E
13
A
45.75
HOLE A: 3.5mm DIAMETER; HOLE E: 5.0mm DIAMETER
ALL DIMENSIONS IN MILLIMETRES

Fig.4: follow this diagram to mark out and drill the two additional holes in the front panel.



This photo shows the wiring to DPDT toggle switch S1, to CON3 and to the main PCB where the 1kΩ resistor was removed (ie, just behind CON3).

The remaining two conductors are taken to two pins of IC18. In this case, the wire from CON6 pin 3 goes to pin 2 of IC18, while the one from CON6 pin 4 goes to pin 7 of IC18.

All that remains is to fit whatever combination of jumper shunts you wish to LK1 and LK2 (just to the left of IC3 on the add-on logic PCB), to program it for the beep duration you want, and then plug each of the three interconnecting ribbon cables into their correct pin headers (ie, into CON5, CON6 and CON7). That done, you should be able to refit the case lid to the counter and apply power to get it all working again.

Don't be surprised when the counter emits a beep as soon as power is turned back on. This doesn't indicate any sort of problem; it's just a quirk of the 4541B timer IC, which produces an output pulse as soon as power is applied.

Final comments

This circuit is certainly a worthwhile addition to the *12-Digit High-Resolution Counter*, especially if you will be making high-resolution measurements. Of course, such measurements will be very time-consuming compared to a counter which has interpolation technology instead of the long-term averaging system we used in the January 2014 and February 2014 design.

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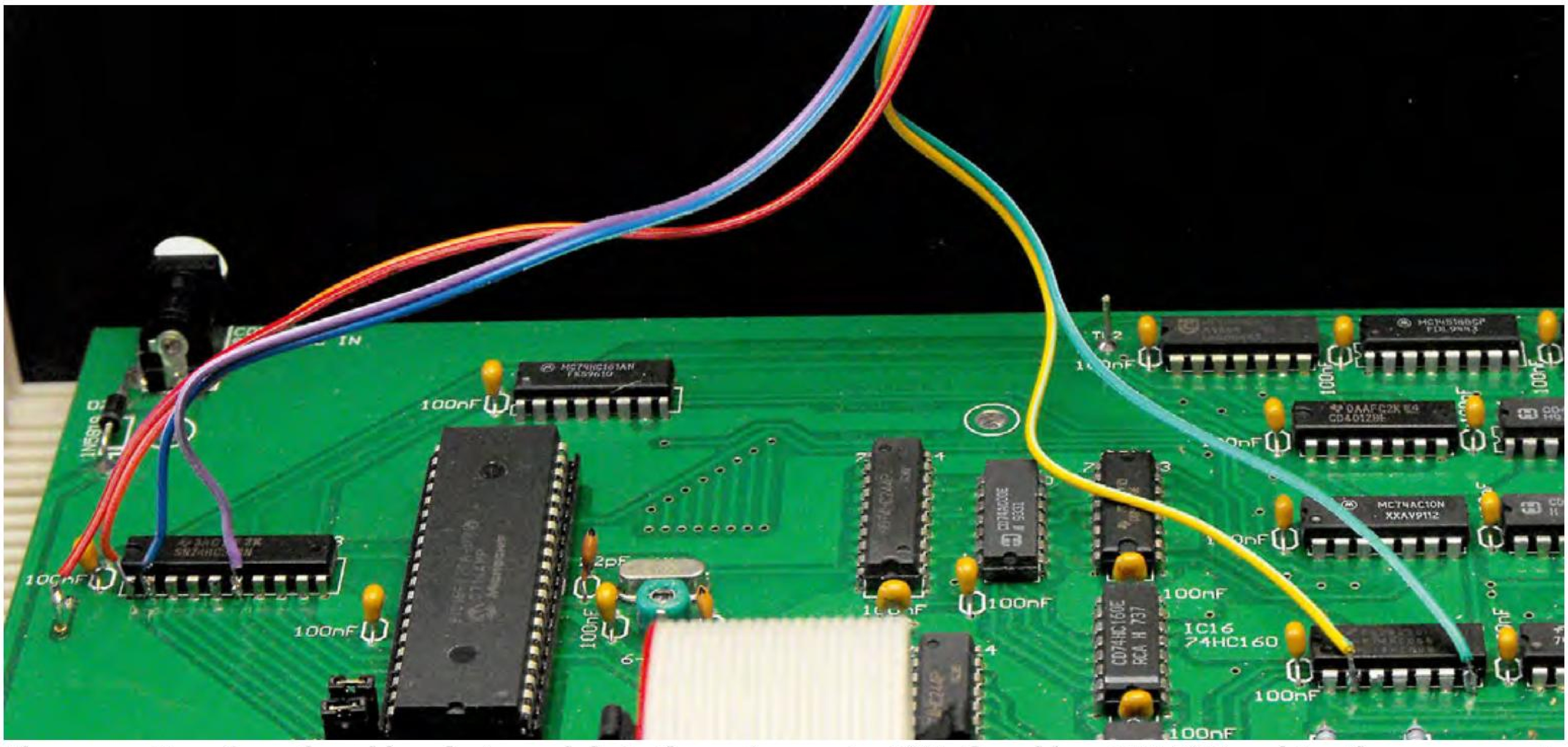

The connections from the add-on logic module to the main counter PCB, the add-on LED PCB and to other components are run using ribbon cable.

TechnoTalk

Entirely natural

Mark Nelson

Back in the April issue we looked at bacteria that fed on electricity, plants that could act as electronic sensors and nanowires composed of microbes. Mark Nelson finds this stuff so fascinating that this month's article brings you more bio-electrical weirdness.

ON REFLECTION, 'WEIRDNESS' is perhaps not the best word to have used. It's a rather 'non-PC' word to use for describing the electrical interaction of living organisms, when all they are doing is a process that occurs entirely naturally. In fact, it's all rather wonderful, so do please read on!

Green electricity grown in Cambridge

Here's a practical electronic project you can definitely try at home. Well, probably. It's a prototype 'green bus shelter' that could eventually generate enough electricity to light itself, but you could use the same technique to illuminate your outdoor electronic development environment (garden shed). In a nutshell, you create a low environmental impact 'hub' to generate electrical current purely from plant power. Amazingly, 'green wall' technology and semi-transparent solar panels can be combined to generate electrical current from a renewable source of energy both day and night.

Sounds too good to be true? Yes. Sounds expensive? Yes, for now. Sounds a bit technical? Yes, but a prototype has been built by a collaboration of researchers at the University of Cambridge and eco-companies, so it must be feasible. You can visit this ongoing living experiment, hosted at the Cambridge University Botanic Garden, which is open to the public. Eight vertical green wall units – created by green-wall specialists Scotscape – are housed along with four semi-transparent solar panels and two flexible solar panels provided by Polysolar. The whole ensemble is incorporated in an architect-designed wooden hub that resembles a bus shelter (to them) and a garden shed (to me!).

Moss-powered radio too

The project is the brainchild of Professor Christopher Howe and Dr Paolo Bombelli of the Department of Biochemistry at Cambridge University. A previous experiment of theirs involved a device able to power a radio using the current generated by growing moss. Plant power is used again in their new hub, which has specially adapted vertical green walls that harvest electrons produced naturally as a by-product of photosynthesis and metabolic activity and converts them into electrical current. The thin-film solar panels turn light into electricity by using mainly the blue and green radiation of the solar spectrum. Plants grow behind the solar glass, 'sharing the light' by utilising the red spectrum radiation needed for photosynthesis, while avoiding the scorching effect of UV light. The plants generate electrical currents as a consequence of photosynthesis and metabolic activity during the day and night (says the press release).

Comments Dr Bombelli, 'Ideally, you can have the solar panels generating during the day, and the biological system at night. To address the world's energy needs, we need a portfolio of many different technologies, and it's even better if these technologies can operate in synergy.'

Electronic bacteria at work

The green wall panels in the hub are made from a synthetic material containing pockets, each holding a litre of soil and several plants. The pockets are fitted with a lining of carbon fibre on the back, which acts as an anode to receive electrons from the metabolism of plants and bacteria in the soil, and a carbon/catalyst plate on the front which acts as a cathode. When a plant photosynthesises, energy from the sun is used to convert carbon dioxide into organic compounds that the plant needs to grow. Some of the compounds – such as carbohydrates, proteins and lipids – are leached out into the soil, where they are broken down by bacteria, which in turn release by-products, including electrons, as part of the process.

Electrons have a negative charge so, when they are generated, protons (with a positive charge) are also created. When the anode and cathode are connected to each other by a wire acting as an external circuit, the negative charges migrate between those two electrodes. Simultaneously, the positive charges migrate from the anodic region to the cathode through a wet system, in this case the soil. The cathode contains a catalyst that enables the electrons, protons and atmospheric oxygen to recombine to form water, thus completing the circuit and permitting an electrical current to be generated in the external circuit.

Practical prospects

Dr Bombelli explains: 'The long-term aim of this solar hub research is to develop a range of self-powered sustainable buildings for multi-purpose use all over the world, from bus stops to refugee shelters.' Meanwhile the hub, with its combination of glass, plants and solar panels, creates a fascinating attraction in Cambridge University's Botanic Garden, where members of the public can track the findings in real time on a computer embedded in the hub itself. There is also a dedicated website at **http://131.111.37.52/index.php** (the computer running at the P2P is not powered using the electrical current generated in the hub – perhaps they should have used a raspberry-plant-powered Raspberry Pi!).

More electric bacteria

A couple of months back, *New Scientist* magazine reported that bacteria have been found growing on tiny magnetic particles, which they use as natural rechargeable batteries. The discovery that tiny crystals of magnetite, a common magnetic mineral, can be used as both electron acceptors and electron donors for the bacteria, working like a battery, was made by a team led by James Byrne of the University of Tübingen in Germany. Byrne grew mixed colonies of two different types of bacteria on magnetite in the laboratory, discovering that magnetite gave electrons to one bacterium and received them from the other.

He explains that in the wild, the two reactions probably happen during day and night cycles or tide phases, with each type of bacteria active at different times. Lars Peter Nielsen, a researcher into microbial processes at Aarhus University in Denmark, supports the idea that magnetite crystals can act like rechargeable batteries. In his view, the discovery demonstrates how magnetite can act as a conductor, sink and source of electrons, depending on the needs of the microbes.

Win a Microchip PICDEM LCD 2 Demonstration Board

EVERYDAY PRACTICAL ELECTRONICS is offering its readers the chance to win a Microchip PICDEM LCD 2 Demonstration Board. The Board (DM163030) shows the main features of Microchip's 28, 40, 64 and 80-pin LCD Flash PIC microcontrollers, including the LCD voltage booster and contrast controller. It is populated with the PIC18F87J90. A sample LCD glass display is included for custom prototyping. The glass features 7-segment displays, wipers, thermometers, star bursts and other common icons.

Some of the applications included are: a voltmeter, which measures the voltage of the on board potentiometer and displays a voltage between 0.00V and 3.30V on the LCD; and a thermometer that measures the voltage of the thermistor and continuously displays the temperature in both Celsius and Fahrenheit. The timer/clock function displays hours:minutes:seconds with a moving second hand, using an on board 32kHz watch crystal. Also, when using the PIC18F87J90 family of devices the LCD module can be configured as a charge pump and software contrast control is activated.

WORTH
$125.00
(approx. £80.00)
EACH
PICDEM LCD 2
MICROCHIP

March 2015 ISSUE WINNER

Mr Stacey Finn, who works at Odstock Medical Limited, Salisbury, UK.

He won a 3DTouchPad valued at £64.00.

HOW TO ENTER

For the chance to win a Microchip PICDEM LCD 2, please visit:
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CLOSING DATE

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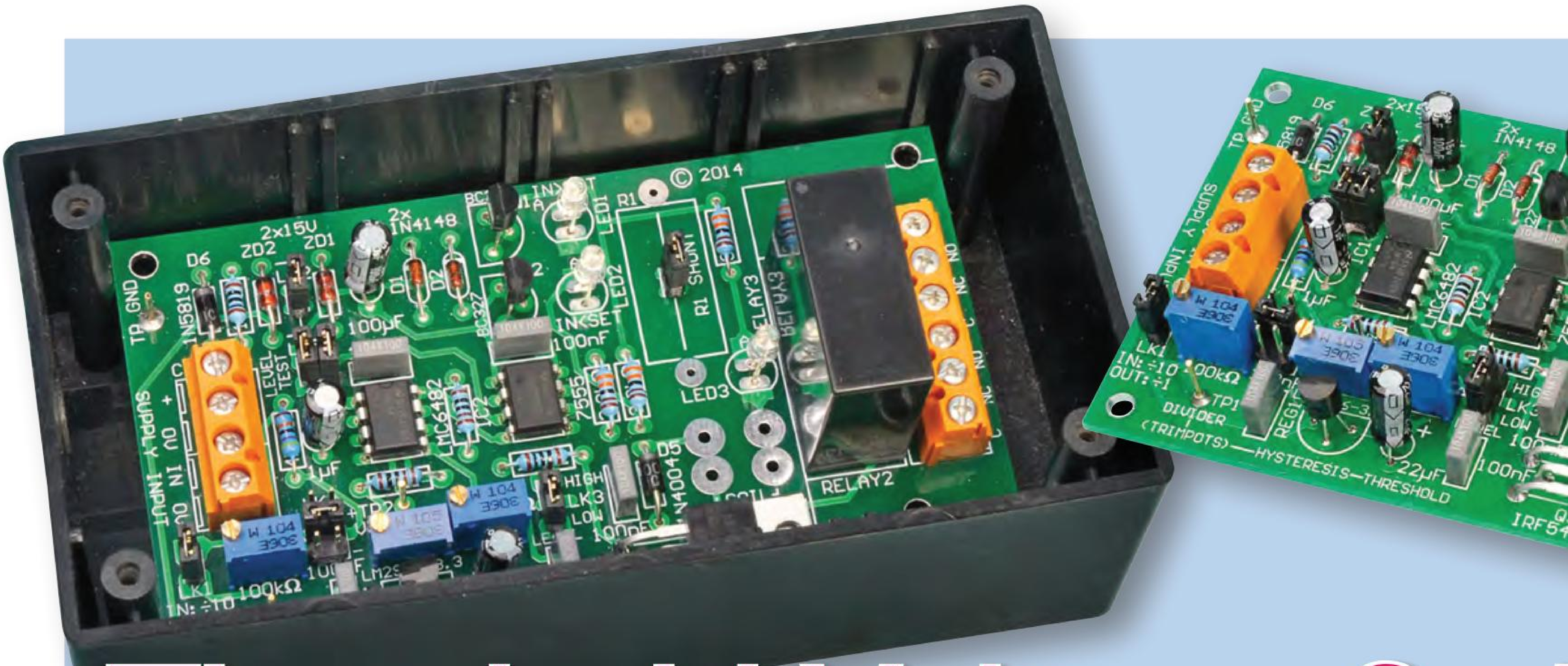


Threshold Voltage Swi

A simple but versatile device to switch a relay w input voltage crosses a preset threshold

This *Threshold Voltage Switch* takes the output of an analogue sensor, battery voltage or other varying voltage and switches power to a motor, warning light or similar when a preset threshold voltage is reached. It can be set up for use with a 5V, 12V or 24V supply. It can also be used to prevent a lead-acid battery from being over-charged.

WHEN MONITORING A SENSOR or any DC voltage signal, you may wish to switch power to a load on or off when a set voltage is reached. This means that at a particular temperature, pressure, fuel mixture or battery voltage, you can switch power to drive a cooling fan, a warning light, battery-charging circuit or whatever you fancy.

Switching is done via a relay that can handle a relatively high current. The relay also provides isolation between the *Threshold Voltage Switch* (*TVS*) sensing circuitry and the load it controls. So there is no requirement to power the *TVS* from the same power supply as the load it controls.

It also does not matter where you put the relay contacts within the load circuit. So the relay can switch the positive or negative supply to the load, as depicted in Fig.1.

Fig.1A shows the load's ground connection being switched while Fig.1B shows the switch in the positive supply connection. Either way, the effect is the same – but it may be more convenient or even a requirement to switch one or the other, depending on your application.

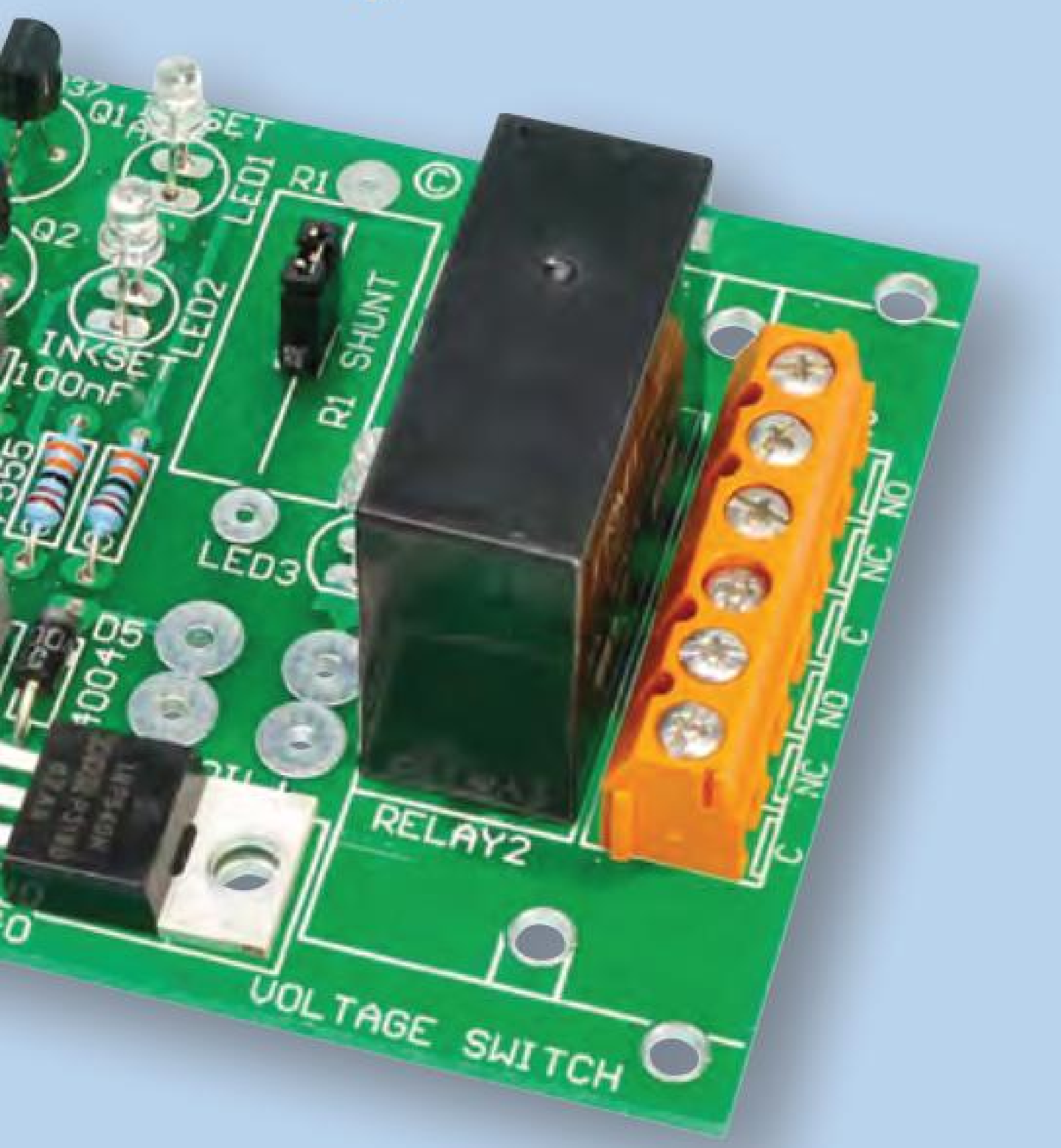
The relay can be switched on when the sensed voltage rises above a preset value or falls below a preset value. This is selected by links on the PCB.

Circuit description

Fig.2 shows the complete circuit for the *TVS*. It comprises two ICs, a 3-terminal regulator, the relay and a few other components.

Op amp IC1a is wired as a voltage comparator to monitor the input (signal) voltage and compare it against a threshold voltage. The input voltage is fed via a 470kΩ resistor to pin 2, the inverting input, while the threshold comparison voltage is fed to pin 3. If the required voltage threshold is above 3.3V, you will need to attenuate the input voltage and this is done by inserting link LK1. The amount of attenuation is adjusted with multi-turn trimpot VR1.

By JOHN CLARKE



itch

when an

Main features

- Operates from 5-24V DC (nominal, 30V maximum)
- Adjustable trigger threshold
- Trigger on high or low voltage
- Output state indicator LEDs
- Multiple relay options, up to 60A SPDT or 10A DPDT

Specifications

Power supply: 5-30V.

Current drain: <1mA with indicator LEDs off (LK4 out), relay off and VR2 set to >100kΩ. With the relay on, the current is dependent on the coil resistance.

Signal input impedance: 470kΩ minimum.

Trigger threshold: adjustable.

Input divider: divide by 1 (LK1 out) or divide by greater than 5.7 (LK1 in).

Hysteresis for no input attenuation: ~5mV-2.5V for 5V supply; ~12mV-6V for 12V supply.

Hysteresis for 10:1 input attenuation: ~50mV minimum for 5V supply; ~120mV minimum for 12V supply.

Maximum switching voltage: 60V DC/40VAC for on-board relay; limited by contact ratings for off-board relay.

A 3.3V reference voltage is provided by REG1, an LM2936 low-quiescent-current, low-dropout regulator which is fed from the V+ supply rail. It feeds trimpot VR3 and in turn, its wiper voltage is fed to IC1b which acts as a low-impedance buffer to provide the reference voltage to pin 3 of IC1a.

Trimpot VR2 adjusts the hysteresis of comparator IC1a. Hysteresis can be regarded as positive feedback and it reduces the sensitivity of the comparator to short-term variations in the input voltage.

To explain further, say the threshold voltage at pin 3 is 3V and the sensed voltage at pin 2 goes slightly above 3V, resulting in the comparator's output going low. The feedback connection from output pin 1 to pin 3 means that the voltage at pin 3 is pulled slightly lower than it was before pin 1 flicked low. That means that the sensed voltage at pin 2 will have to drop somewhat below 3V to cause the comparator to change state again. So the output will not switch again immediately if there is only a slight drop in the voltage at pin 2 immediately after the output switches.

Conversely, when IC1a's output goes high (near V+) in response to a dropping voltage at pin 2 of IC1a, pin 3 is instead pulled higher than before and pin 2 will have to rise by an increased amount to switch the comparator's output low again. So the threshold voltage for IC1a varies depending on the output of IC1a.

In practical terms, hysteresis prevents the relay from 'chattering' on and off when the sensed voltage is near the voltage threshold, and stops the circuit from switching on and off every few seconds. Imagine you design a fan to cool a heatsink when the temperature reaches 60°C. As the temperature sensor reaches 60°C, the fan will run and almost immediately the temperature will drop by a small amount.

This means, without hysteresis, the fan might run for a less than a second before switching off and then a second or so later, it will be on again as the 60°C threshold is reached. By adding hysteresis, the fan can be set to start running at 60°C but only switch off at say 55°C. That way, the fan will run for longer, preventing rapid on-and-off cycling.

When setting the threshold voltage for IC1a, we monitor test point TP2. This actually allows us to set the two switching thresholds: one when IC1a's output is high and the second when its output is low. The threshold measurement is made between test points TP2 and TP GND.

IC2, a CMOS 7555 timer, is used as an inverter and its pin 3 output goes to one side of 3-way header LK3. Depending on how link LK3 is set, the

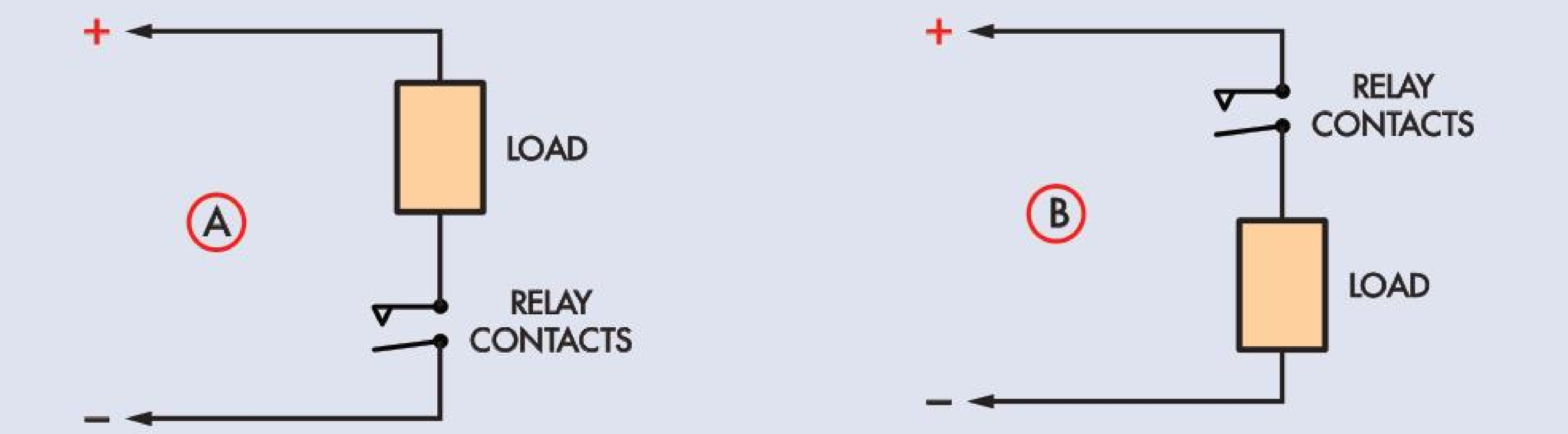


Fig.1: the relay can switch either the positive or negative supply lead to the load. Fig.1A shows the load's ground connection being switched; Fig.1B shows the relay contacts in the positive supply lead.

Parts List

1 double-sided PCB with plated-through holes, available from *EPE PCB Service*, code 99106141, 107 × 61mm
1 UB3 plastic utility case, 130 × 68 × 44mm (optional)
1 12V DPDT relay (RELAY1) (Altronics 8A S4190D or low-profile S4270A, Jaycar 5A SY-4052)*
2 2-way PCB-mount screw terminals, 5.08mm spacing (CON1)
2 3-way PCB-mount screw terminals, 5.08mm spacing (CON2)#
2 8-pin DIL IC sockets (optional)
5 2-way SIL pin headers with 2.54mm pin spacings (LK1, LK2, LK4, LK5a and LK5b)
1 3-way SIL pin header with 2.54mm pin spacing (LK3)
6 jumper shunts (shorting blocks)
3 PC stakes (TP GND,TP1,TP2)
1 M3 × 6mm machine screw/nut

Semiconductors

1 LMC6482AIN dual CMOS op amp (IC1)
1 7555 CMOS timer (IC2)
1 BC337 NPN transistor (Q1)
1 BC327 PNP transistor (Q2)
1 IRF540 N-channel MOSFET (Q3)
1 LM2936-3.3 3.3V regulator (REG1)
2 1N4148 small signal diodes (D1,D2)
1 1N4004 1A diode (D3)
1 1N5819 Schottky diode (D4)
1 1N4744 15V Zener diode (ZD1) (two required for 24V supply)
2 3mm red LEDs (LED1,LED2)
1 3mm green LEDs (LED3)
2 100kΩ 25-turn trimpots (VR1,VR3)
1 1MΩ 25-turn trimpot (VR2)

Capacitors

1 100µF 16V radial electrolytic
1 22µF 16V radial electrolytic
1 1µF 16V radial electrolytic
5 100nF MKT

Resistors (0.25W, 1%)

1 470kΩ
3 3.3kΩ (0.5W)
2 1kΩ
2 100Ω^
Plus R1 (5W) if required (see text)

Notes

* see text and Table 1 for other relay options.
# not required if an off-board relay is used; two PCB-mount vertical spade connectors plus matching crimp connectors are required instead.
^ For 5V supply, delete 1 × 100Ω resistor and add 1 × 10Ω; for 24V supply use 220Ω 0.5W.

gate drive for MOSFET Q3 can come from either pin 1 of IC1a or pin 3 of IC2. This means that the relay can be turned on when the input voltage exceeds the threshold (LK3 set to HIGH) or when the input voltage goes below the threshold (LK3 to LOW).

As shown, the HIGH setting selects the output from IC2, while the low setting selects IC1a's output. The selected output then drives MOSFET Q3 via a 100Ω gate resistor. When Q3's gate goes high, Q3 turns on and powers the relay coil. LED3 (green) is also lit whenever Q3 is switched on.

Note that although Q3 isn't a logic-level MOSFET, it's suitable for use with a 5V supply which results in the MOSFET gate drive being less than 5V. We have specified an IRF540 MOSFET for this reason – it doesn't need to fully saturate as it's only switching a small current (the relay coil current).

Output indication

LED1 and LED2 are used to indicate IC2's output level and are selected by links LK5a and LK5b. They simply indicate whether the input signal is above or below the threshold voltage. LED1 is driven by NPN emitter-follower transistor Q1, while LED2 is driven by PNP emitter-follower Q2.

In operation, LED1 lights when the input is greater than the threshold, while LED2 lights when the input is less than the threshold. After setting up the threshold adjustments, the two LK5 jumper shunts can be removed so that these LEDs no longer light. This reduces the current drain of the circuit, which can be useful in situations where current drain must be minimised.

Supply voltage

The circuit can be operated from supply voltages ranging from 5-30V. Most of the circuit is fed via Schottky diode D4, while the relay is directly powered from the input supply.

D4 is included for reverse-polarity protection. It's followed by a 100Ω resistor (R2), while Zener diode ZD1 is included to clamp the supply to 15V. ZD2 is used to drop the supply by 15V when a 24V supply is connected, while LK2 is used to short ZD2 out if the supply voltage is below 15V. A 100µF electrolytic capacitor filters the resultant supply.

Note that the 100Ω resistor (R2) in series with D4 should be reduced to 10Ω if a 5V supply is used.

If the supply voltage is significantly more than the voltage rating of the relay, it will need a resistor in series with the coil. This is shown on the circuit as R1. As previously stated, the relay is driven by MOSFET Q3. If the voltage rating of the relay coil is close to the supply voltage, resistor R1 is omitted and link LK4 inserted instead.

Do not be concerned about the normal voltage variation which can be expected from 12V or 24V lead-acid batteries. A 12V battery may go as high as 14.8V while being charged, while a 24V battery can go to 29.6V. Both 12V and 24V relays can cope with this variation and there is no need for a series dropping resistor.

Diode D3 and its associated 100nF capacitor suppress the back-EMF transient when the relay switches off.

Construction

The *TVS* is built on a double-sided PCB coded 99106141 and measuring 107 × 61mm which is available from the *EPE PCB Service*. This is designed to clip into the side channels of a plastic UB3 box (130 × 68 × 44mm), with the external leads exiting via a cable gland.

The UB3 box is optional, however. Depending on the application, it may be more convenient to house the PCB inside existing equipment.

Fig.3 shows the parts layout on the PCB. Begin by inspecting the PCB for any defects (rare these days) and checking that the hole sizes for the larger parts are correct. If this checks out, the next step is to select the relay

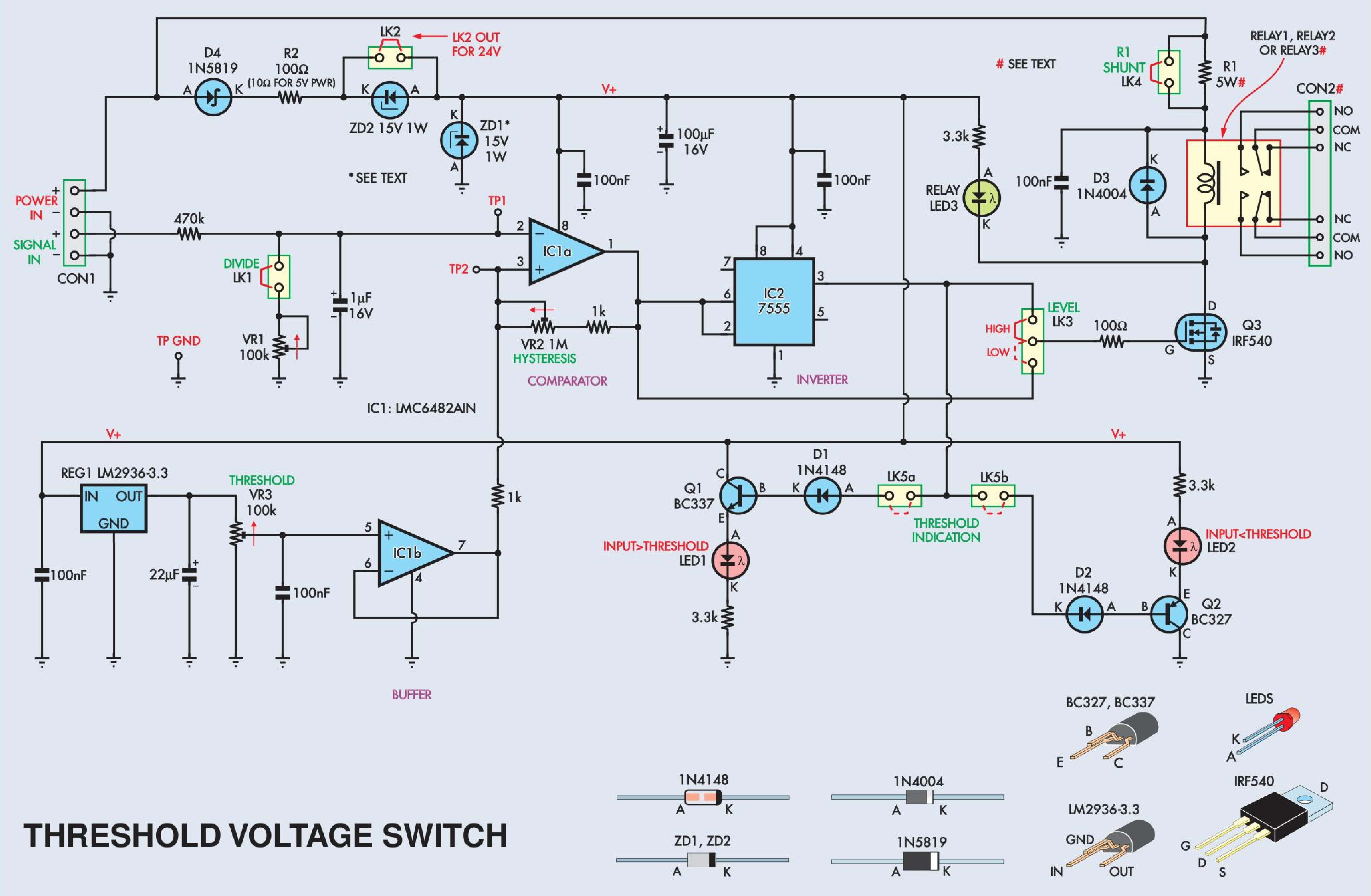
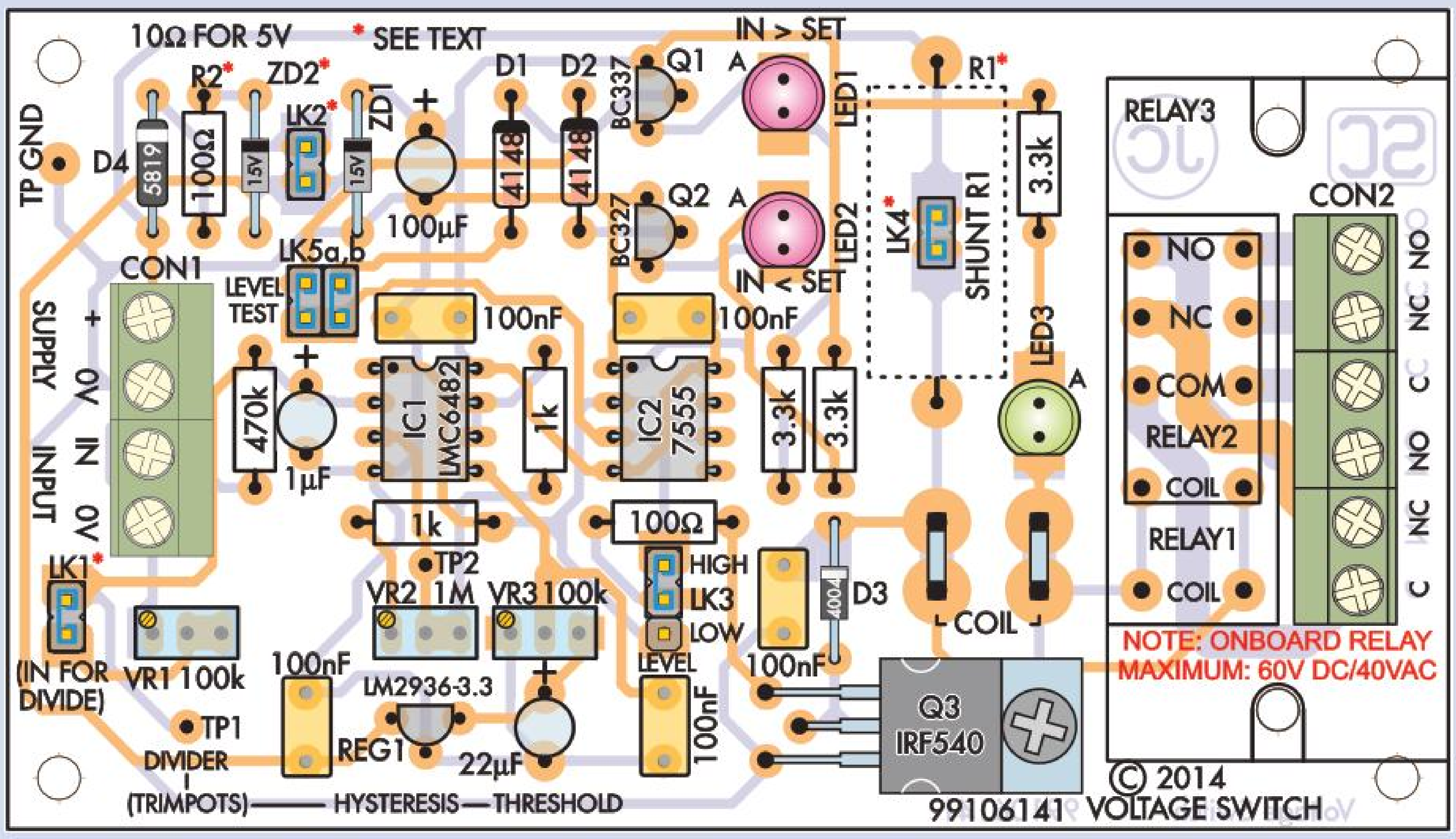

THRESHOLD VOLTAGE SWITCH
POWER IN
SIGNAL IN
CON1
D4 1N5819
R2 100Ω (10Ω FOR 5V PWR)
LK2
LK2 OUT FOR 24V
ZD2 15V 1W
ZD1* 15V 1W
*SEE TEXT
V+
470k
DIVIDE LK1
VR1 100k
1µF 16V
TP GND
TP1
TP2
IC1a
COMPARATOR
VR2 1M HYSTERESIS
1k
100nF
100µF 16V
IC2 7555
INVERTER
IC1: LMC6482AIN
3.3k
RELAY LED3
100nF
D3 1N4004
# SEE TEXT
R1 SHUNT LK4
R1 5W#
RELAY1, RELAY2 OR RELAY3#
CON2#
NO
COM
NC
LEVEL LK3
HIGH
LOW
100Ω
Q3 IRF540
REG1 LM2936-3.3
IN
OUT
GND
22µF
THRESHOLD VR3 100k
IC1b
BUFFER
Q1 BC337
INPUT>THRESHOLD LED1
D1 1N4148
LK5a
LK5b
THRESHOLD INDICATION
D2 1N4148
Q2 BC327
INPUT<THRESHOLD LED2
1N4148
ZD1, ZD2
1N4004
1N5819
BC327, BC337
LM2936-3.3
LEDS
IRF540

Fig.2: the complete circuit of the *Threshold Voltage Switch*. Op amp IC1 is wired as a voltage comparator and this compares the input (signal) voltage fed in via CON1 with a threshold voltage set by REG1 and VR3 (and buffered by IC1b). IC2 operates as an inverter, while LK3 selects either the output from IC1a or IC2 to drive MOSFET Q3, which in turn switches the relay. LED1 and LED2 provide threshold switching indication, while LED3 indicates when the relay is on.


10Ω FOR 5V
* SEE TEXT
TP GND
D4
5819
R2*
100Ω
ZD2*
15V
LK2*
ZD1
15V
100µF
D1
4148
D2
4148
BC337
Q1
IN > SET
A
LED1
R1*
3.3k
RELAY3
CON2
NO
NC
C
Q2
BC327
LED2
IN < SET
LK4*
SHUNT R1
LED3
CON1
LK5a,b
LEVEL TEST
100nF
100nF
SUPPLY INPUT
+
0V
IN
0V
470k
1µF
IC1
LMC6482
1k
IC2
7555
3.3k
3.3k
COM
RELAY2
COIL
RELAY1
1k
100Ω
TP2
HIGH
LK3
LOW
LEVEL
LK1*
VR2 1M
VR3 100k
4004
D3
COIL
NOTE: ONBOARD RELAY MAXIMUM: 60V DC/40VAC
(IN FOR DIVIDE)
VR1 100k
100nF
LM2936-3.3
100nF
Q3
IRF540
TP1
DIVIDER
REG1
22µF
(TRIMPOTS)
HYSTERESIS
THRESHOLD
© 2014
99106141
VOLTAGE SWITCH

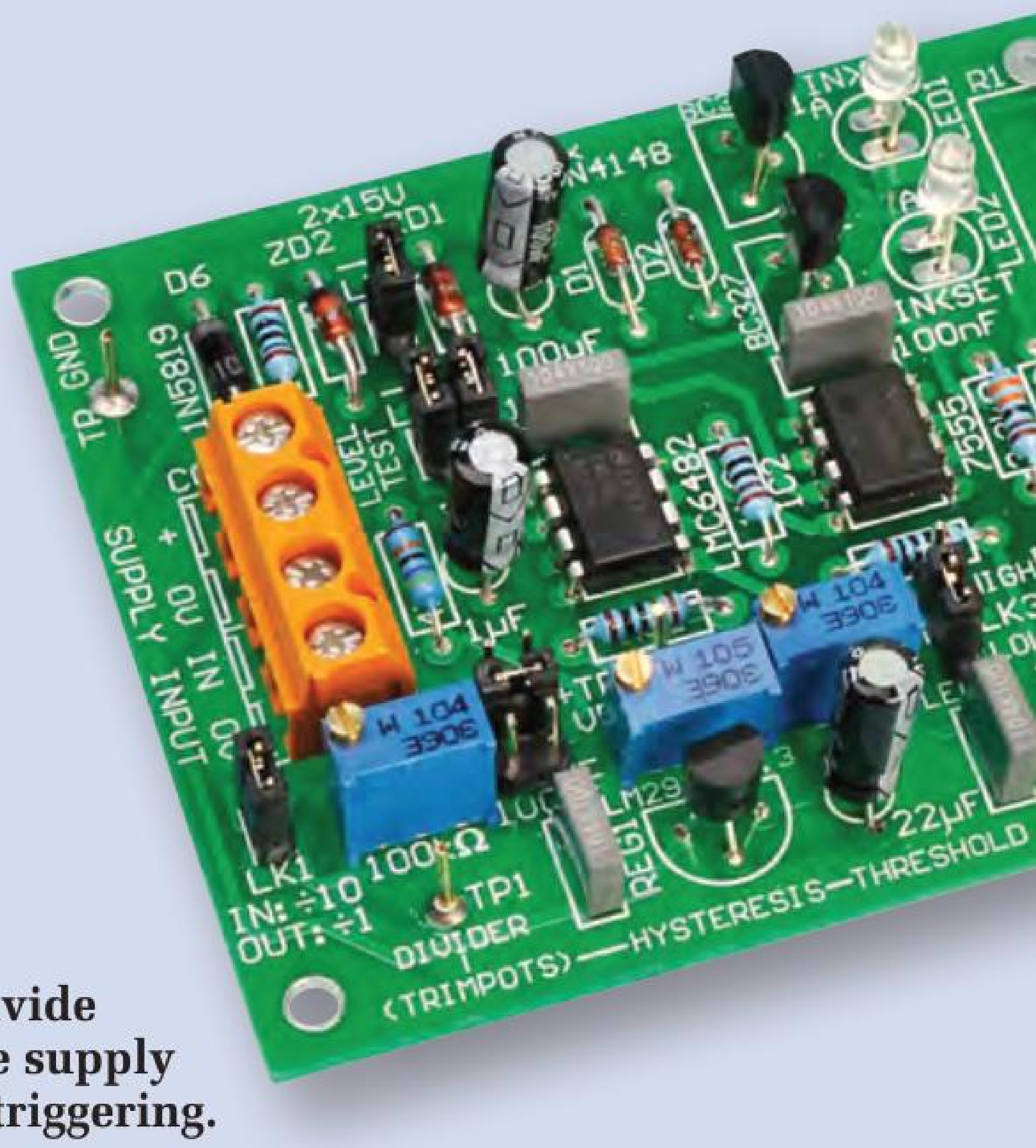


Fig.3: follow this diagram to build the *TVS* with an on-board relay. Install LK1 to divide the input signal, remove LK2 and install ZD2 for a 24V supply and install LK4 if the supply voltage doesn't exceed the relay rating (see text). LK3 selects high or low threshold triggering.

to be used from Table 3 (near the end of this article).

Choosing the relay

Basically, there are several different relays that can be used with the *TVS*. The overlay shows a standard 12V DPDT relay set up. It's just a matter of selecting a relay that suits your application.

Note that LK4 is fitted for most relays. However, if the supply voltage exceeds the voltage rating of the relay to be used, then LK4 is left out and 5W resistor R1 is fitted instead. R1 is wired in series with the relay coil to drop the voltage.

The value required for R1 is easily calculated. For example, if the relay coil is rated at half the supply voltage (eg, a 12V relay with a nominal 24V supply), then the resistor needs to have about the same resistance as the relay coil. In other cases, you can calculate the required value for R1 as follows:

1) Subtract the relay coil voltage from the power supply voltage and multiply the result by the coil resistance
2) Divide the result obtained in step 1 by the relay coil voltage to obtain the resistor value required.

For example, to run a 12V relay with a coil resistance of 120Ω from an 18V supply, you will need a 60Ω 5W series resistor. This is calculated as ((18 – 12) × 120Ω) ÷ 12. If the calculated value is not a standard 5W resistor value, choose the next highest available value. **As stated earlier, for a 5V supply, resistor R2 must be 10Ω.**

Regulating the supply

By carefully choosing the values for ZD1 and ZD2, the supply for IC1 can be regulated. However, this is only required if the threshold voltage must have a very high precision, ie, the swing in the input voltage being monitored is below 100mV. The 3.3V reference is quite stable, but it will vary by about 1mV for each 1V variation in the V+ rail.

Another reason for a regulated supply is that it makes for a more consistent hysteresis voltage.

For example, if a 12V lead-acid battery is used to power the *TVS*, the supply can vary from 11.5V to 14.8V. In that case, changing ZD1 to 10V will minimise any change in the threshold or hysteresis as the supply varies.

Similarly, for a 24V battery, both ZD1 and ZD2 can be 10V types. The point is to ensure that the supply voltage always exceeds the sum of the values of ZD1 and ZD2, but ZD1 must be between 5.1V and 15V. Resistor R2 can remain at 100Ω 0.5W for a 12V supply, but should be changed to 220Ω 0.5W for a 24V supply.

Installing the parts

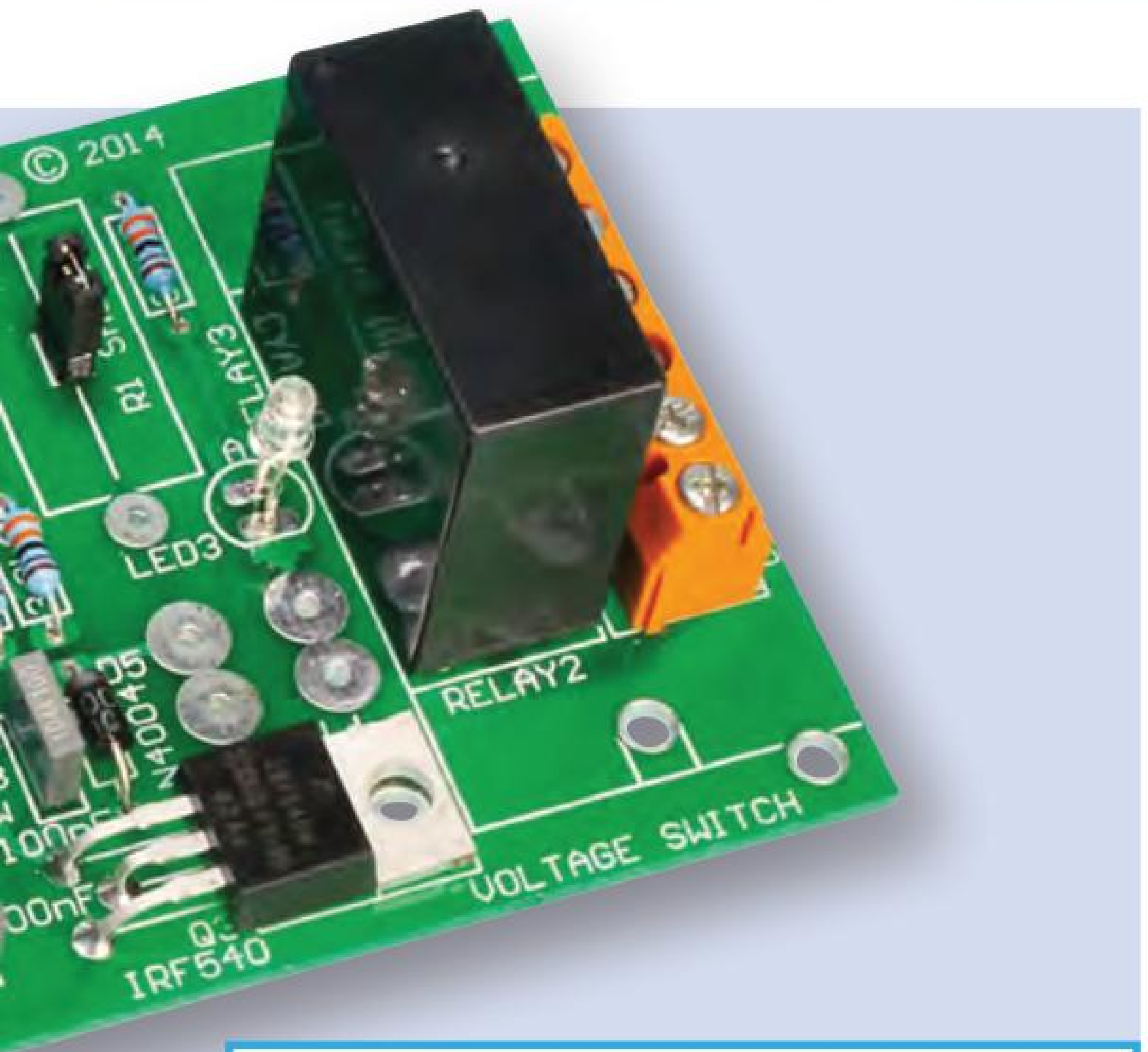
Once you've decided on the relay and supply regulation option, you can begin installing the parts on the PCB. The resistors, diodes and Zener diodes can go in first. Table 1 shows the resistor colour codes, but a digital multimeter should also be used to check each resistor before soldering it into place.

Make sure that the diodes and Zener diodes are installed with the correct polarity, ie, with the striped end of each device oriented as shown on Fig.3. Note that ZD2 is not required if you intend using a supply of 12V or less (LK2 is fitted later instead).

The three PC stakes can go in next, one at TP GND and the others at TP1 and TP2. Follow these with MOSFET Q1 – it's mounted horizontally and secured to the PCB using an M3 × 6mm screw and nut. Bend its leads at right

Table 1: Resistor Colour Codes

☐	No.	Value	4-Band Code (1%)	5-Band Code (1%)
☐	1	470kΩ	yellow violet yellow brown	yellow violet black orange brown
☐	3	3.3kΩ	orange orange red brown	orange orange black brown brown
☐	2	1kΩ	brown black red brown	brown black black brown brown
☐	2	100Ω	brown black brown brown	brown black black black brown



Maximum switching voltages for the TVS

Although its contacts may be rated higher, the maximum switching voltage for the on-board relay is 60V DC or 40VAC. **Do not try to switch mains voltages using an on-board relay, as the tracks on the PCB are too close together.**

If you do want to switch mains, you will need to use an off-board relay that has contacts rated for 230VAC. Many will be rated for 230VAC, but those designed for automotive applications (eg, horn relays) will not be.

angles before mounting it into position and be sure to fasten its tab to the PCB before soldering the leads.

REG1, Q1 and Q2 are next on the list. Be sure to use the correct device at each location and note particularly that Q1 is a BC337, while Q2 is a BC327 (don't get them mixed up). IC1 and IC2 can then go in, again taking care not to get them mixed up and making sure that they are oriented as shown (ie, pin 1 at top left). They can either be soldered directly to the PCB or you can use IC sockets.

Now for the capacitors. The electrolytic types must be installed with the polarity shown (the longer lead being positive), while the MKT capacitors can be mounted either way around. Once these parts are in, you can fit the various pin headers for the jumper links.

LK1, LK2, LK4, LK5a and LK5b all require 2-way pin headers. Note that the LK4 header must not be installed if resistor R1 is to be fitted. 3-pin header LK3 should also be fitted now.

LEDs and trimpots

The three LEDs can be pushed all the way down onto the PCB or they can be mounted a few millimetres proud of the PCB. Make sure that each LED is oriented correctly, with its anode lead (the longer of the two) going to the pad marked 'A'. A cardboard spacer slid between the leads of each LED when soldering can be used to ensure consistent lead lengths.

Alternatively, if you want the LEDs to later protrude through the lid of the case, then it will be necessary to extend their leads and sleeve them in heatshrink tubing. You could also glue them to the lid and connect them to the PCB via flying leads; you could even fit pin headers in their place and use flying leads terminated in header plugs.

Trimpots VR1-VR3 are straightforward to install. Use the 1MΩ trimpot (code 105) for VR2 and be sure to install them with the adjusting screws to the left.

Now for the screw terminal blocks. CON1 consists of two 2-way terminal blocks and these must be dovetailed together before fitting them to the PCB. Push them all the way down onto the board and check that the wire entry holes are facing outwards before soldering the pins.

CON2 is required if you intend using a PCB-mounted relay. It consists of three 2-way (or two 3-way) terminal blocks and again check that it sits flush against the PCB and is oriented correctly before soldering the pins.

Alternatively, if an external relay with quick connectors is to be used, then the two 6.35mm PCB-mount male spade connectors will need to be installed. These are located just above Q3 and provide the relay coil connections.

Configuration

Once the PCB assembly has been completed, go back over your work and check it carefully. In particular, look for incorrectly oriented parts, parts in the wrong position and missed solder joints. If all is correct, follow this step-by-step procedure to configure the unit:

Step 1 If you are using a 12V or 5V supply, install the jumper shunt for LK2. Alternatively, for a 24V supply, install Zener diode ZD2 and leave jumper shunt LK2 out.

Step 2 Fit jumpers on LK5a and LK5b so that LED1 and LED2 will work.

Step 3 Fit a jumper on LK4 if R1 has not been fitted.

Step 4 Adjust trimpots VR1, VR2 and VR3 clockwise until the end stop clicks can be heard (note: these are 20-turn or 25-turn trimpots).

Step 5 Apply power and check that voltage is present between pins 8 and 4 of IC1. The actual voltage will depend on the supply, Zener diodes ZD1 and ZD2 and whether ZD2 is bypassed.

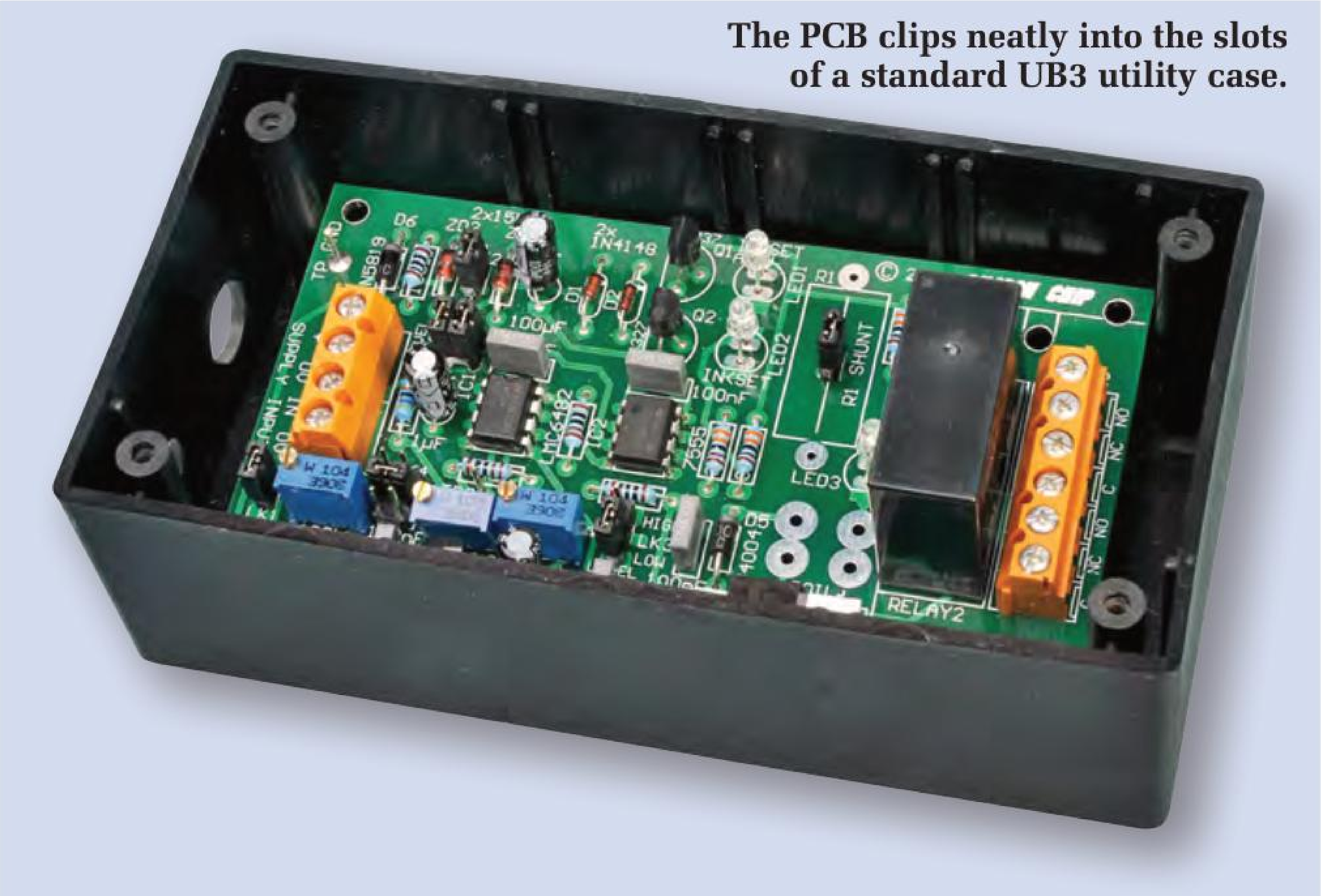
If you are using a 12V supply and a 15V Zener for ZD1 (LK2 in), IC1 should have around 11.7V between pins 8 and 4. For a 5V supply, you should get a reading of about 4.7V. And for a 24V supply (ZD2 in and LK2 out), you should get a reading of about 8.7V.

Input signal level adjustment

LK1 can be installed to allow the input signal to be reduced if the voltage to be monitored is going to exceed 3.3V. To set VR1, apply a voltage similar to that you require for the threshold (say 10V) to the input, switch on and measure the voltage between TP1 and TPG. Adjust VR1 to obtain less than 3.3V at TP1.

Threshold adjustment

The threshold voltage adjustment is done as follows. Apply a voltage at



The PCB clips neatly into the slots of a standard UB3 utility case.

Table 3: Relay options for the TVS

TVS Supply Voltage:	**5V (LK2 in)**	**12V (LK2 in)**	**24V (LK2 out, ZD2 installed**)**
On-board relays (maximum switched voltage = 60V DC or 40VAC)			
1A DPDT PCB mount (RELAY2) Contact rating: 24V DC/40VAC	Altronics S 4147	Altronics S 4150	Altronics S 4152
5A DPDT PCB mount (RELAY1) Contact rating: 30V DC/40VAC		Jaycar SY-4052	Jaycar SY-4053
8A DPDT PCB mount (RELAY1) Contact rating: 30V DC/40VAC		Altronics S 4190D Altronics S 4270A	Altronics S 4195D Altronics S 4272
Off-board relays (maximum switched voltage limited by relay contacts)			
30A (RELAY3)* Contact rating: 14V DC/240VAC		Altronics S 4211 SPDT Jaycar SY-4040 SPST	Use 12V relay. R1=180Ω (for S 4211), 120Ω (for SY-4040) 5W, LK6 out
30A SPST Horn Relay* Contact rating: 14V DC		Altronics S 4335A Jaycar SY-4068	Altronics S 4332 Jaycar: Use 12V relay. R1=82Ω 5W, LK6 out
30A SPDT Horn Relay* Contact rating: 14V DC		Jaycar SY-4070	Use 12V relay. R1=82Ω 5W, LK6 out
60A SPDT Horn Relay* Contact rating: 14V DC		Altronics S 4339 Jaycar SY-4074	Use 12V relay. R1=82Ω 5W, LK6 out

Notes: LK6 installed (jumper in) unless stated.
* Bolt on and quick connector type. Requires 2 × 6.35mm PCB-mount male spade connectors with 5.08mm pin spacing (Altronics H 2094) plus 4 × 6.35mm insulated female spade quick connectors with 4-8mm wire diameter entry (these are not suitable for the 60A relay).
** Install 1N4744 15V Zener ZD2.

A variety of relays can be used with this unit, such as DPDT (double-pole, double-throw), SPDT (single-pole, double-throw) and SPST (single-pole, single-throw). Double-pole (DP) simply means that there are two separate sets of contacts that can be used independently to switch power (or even signals).

Single-throw (ST) and double-throw (DT) contacts each have a common (COM) contact and both ST and DT types have a contact that is open when the relay is off; ie, the normally open or NO contact. This NO contact closes against the COM terminal when the relay is on (ie, the coil is powered).

In relays with DT contacts there is also a normally closed (NC) contact. This connects to the COM terminal when the relay is off and opens when the relay is on.

Both SPDT and DPDT relays give the option of powering something when the relay is either switched on or is switched off. For example, you can set up the TVS so that power is switched on when the relay is off by connecting the load to its supply via the NC and COM contacts. The main reason to do this is to minimise the current drawn by the circuit. The TVS typically draws less than 1mA when the relay is off but when the relay is on, the current drawn by its coil will typically be around 50mA or up to 100mA, depending on the relay used.

Table 3 shows the various relays that can be used with the TVS. The choice depends on the supply voltage and the current to be switched by the relay's contacts.

PCB-mounting relays are accommodated on the PCB and their contacts brought out to screw terminal block CON2. By contrast, relays with quick connect terminals are mounted off the board. You can either use leads fitted with quick connectors or you can solder the leads directly to the terminals.

Since relays with 12V coils are more common than 24V relays, the *TVS* has been designed so that it can use a 12V relay even when operating from 24V. It's just a matter of removing LK4 and installing a dropping resistor (R1) on the PCB, in series with the relay's coil.

Having said that, if you are operating from a 24V supply and can obtain a suitable relay with a 24V coil and the correct pin-out, this will generally halve power and current consumption when the relay is energised. In that case, leave R1 out and install jumper LK4 instead.

the level you want the *TVS* to switch the relay, then adjust VR3 until the threshold voltage is reached. LED1 will light when the input is above the threshold, while LED2 will light when the input is below the threshold.

With VR2 (hysteresis) at maximum, the threshold for a rising input voltage will be similar to that of a falling input voltage. So, hysteresis can be increased by reducing the value of VR2 (turn VR2 anti-clockwise for more hysteresis).

Changing the hysteresis will also affect the threshold voltage previously set using VR3, so you will now need to readjust VR3 to correct this. Once that's done, check that the hysteresis set using VR2 is suitable and repeat the above steps if necessary.

Jumper LK3 determines whether the relay turns on or off for rising or falling threshold voltages. Install LK3 in the HIGH position if you want the relay to turn on when the input voltage exceeds the threshold. Conversely, install LK3 in the LOW position if you want the relay to turn on when the input voltage goes below the threshold.

Finally, if you want to reduce the current drawn by the *TVS* with the relay off, jumpers LK5a and LK5b can be removed (to disable LED1 and LED2) once the set-up procedure has been completed. Alternatively, you may leave them in to monitor the operation of the unit.

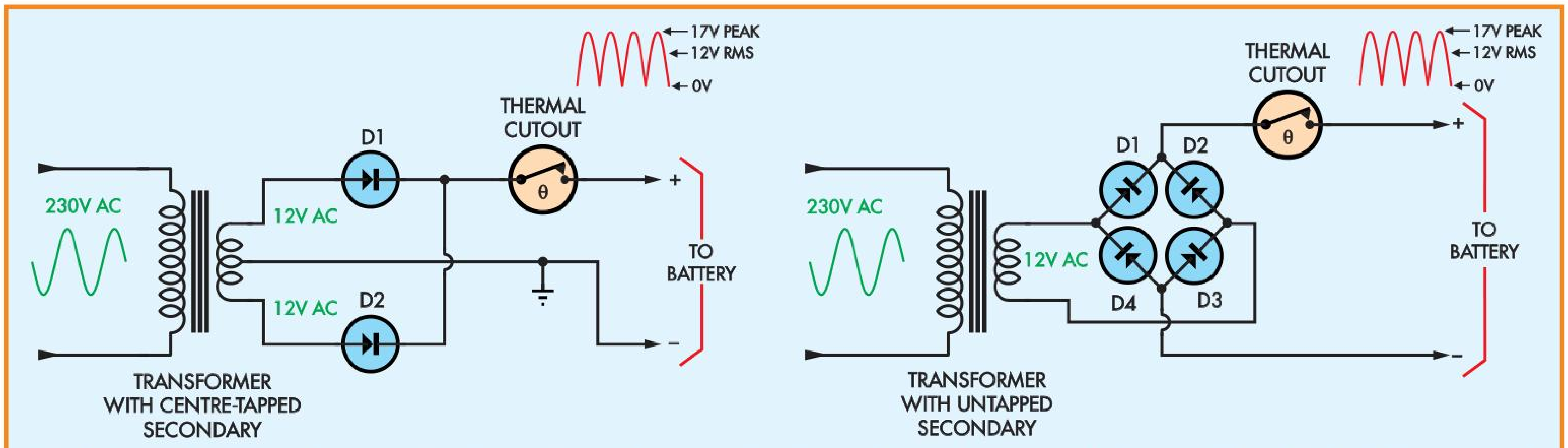


Fig.4: typical battery charger circuitry using either a centre-tapped transformer with two rectifier diodes (A) or a single winding transformer with a four-diode bridge rectifier (B).

Battery charging with the Threshold Voltage Switch

MANY READERS have asked for a simple solution to prevent overcharging of lead-acid batteries. Most simple battery chargers do not have any end-of-charge detection and will continue charging at their full current even though the battery may have reached 14.4V. If allowed to continue for too long, such over-charging leads to severe gassing, excessive fluid loss as the battery overheats and even buckling of the plates. Ultimately, the battery will fail much sooner than it should.

Over-charging can also lead to a build-up of hydrogen gas in an enclosed space, which is an explosion hazard, especially in the presence of sparks (often caused if the battery is disconnected during charging).

An elegant solution to this problem is to use our *Threshold Voltage Switch* (*TVS*) as a battery charge cut-off device and you can then add a trickle charge facility as well.

So why do most battery chargers not limit or stop charging when the battery reaches 14.4V (in the case of a 12V lead-acid battery)? The answer is that most chargers simply comprise a transformer and rectifier supplying raw full-wave rectified voltage to the battery.

Fig.4 shows two typical battery charger circuits. These use either a centre-tapped transformer with two rectifier diodes (A) or a single winding transformer with a four-diode bridge rectifier (B).

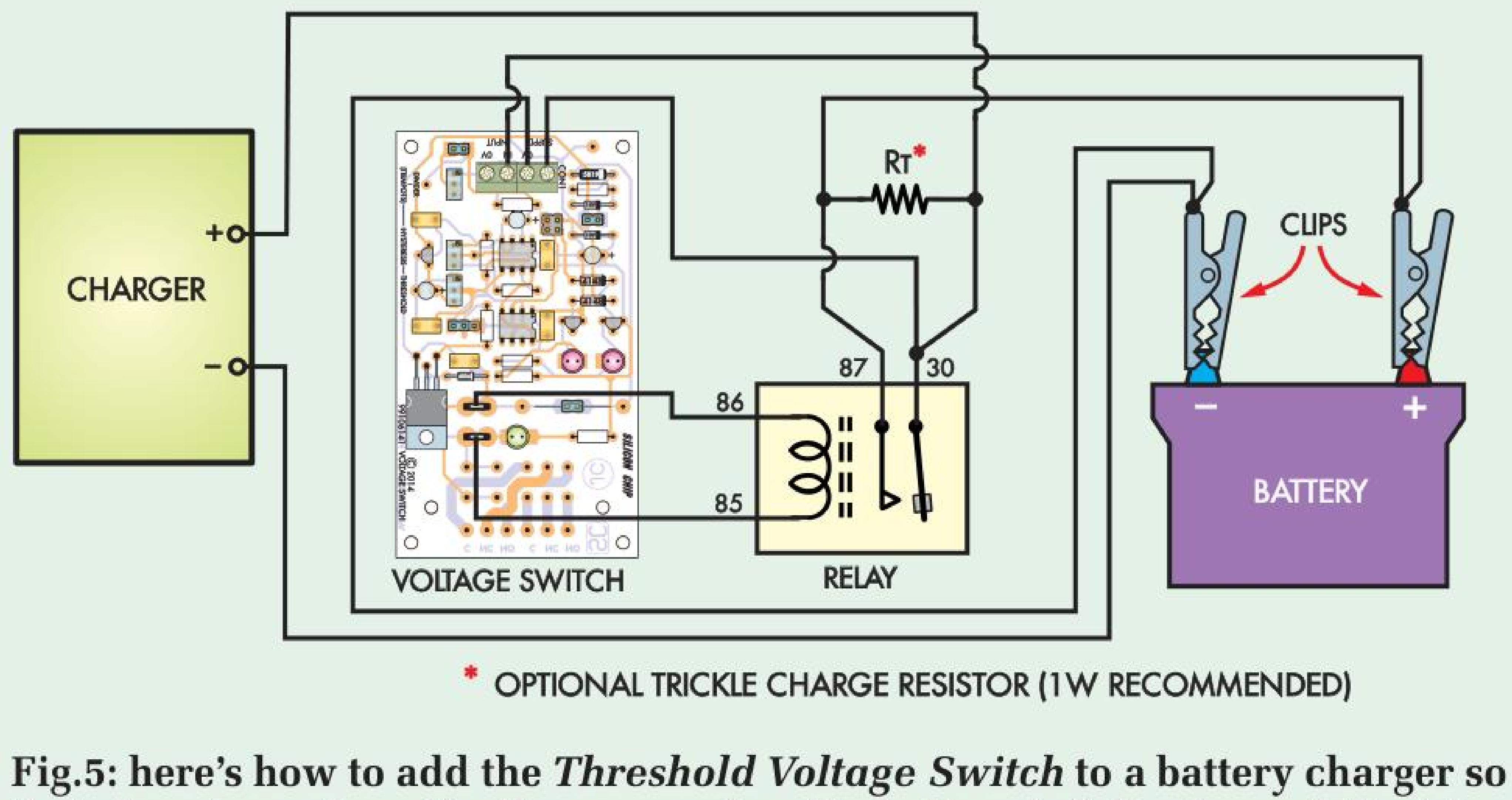
The charger will usually also include a temperature cut-out that switches the charger off when the transformer runs too hot. But there is no facility to sense the battery voltage or stop charging above a certain voltage.

You may have a commercial battery charger that uses a circuit like one of these or you may have built one of the many we have featured over the years. Either way, the charge process can be monitored to ensure that the battery isn't overcharged.

Overcharging can easily occur since these chargers use a nominal 12V (or higher) transformer. The output after rectification is pulsating DC with a peak voltage of around 17V. If the charger is left on charge for too long, the 17V peak can overcharge the battery easily, reaching well beyond 15V if left unattended.

This solution is the *TVS*. It can monitor the battery and switch off the charging current as soon as the voltage reaches 14.4V. Additionally, the hysteresis can be made sufficiently large so that charging does not recommence until battery voltage falls to its 12.6V (typical) resting voltage after charging ceases.

Fig.5 shows the required arrangement. The output from the charger is switched using a 60A 12V relay (Altronics S 4339, Jaycar SY-4074 or similar). This heavy-duty relay is



* OPTIONAL TRICKLE CHARGE RESISTOR (1W RECOMMENDED)

Fig.5: here's how to add the *Threshold Voltage Switch* to a battery charger so that charging automatically ceases when the battery is fully charged. Resistor R_T is optional for trickle charging (see text).

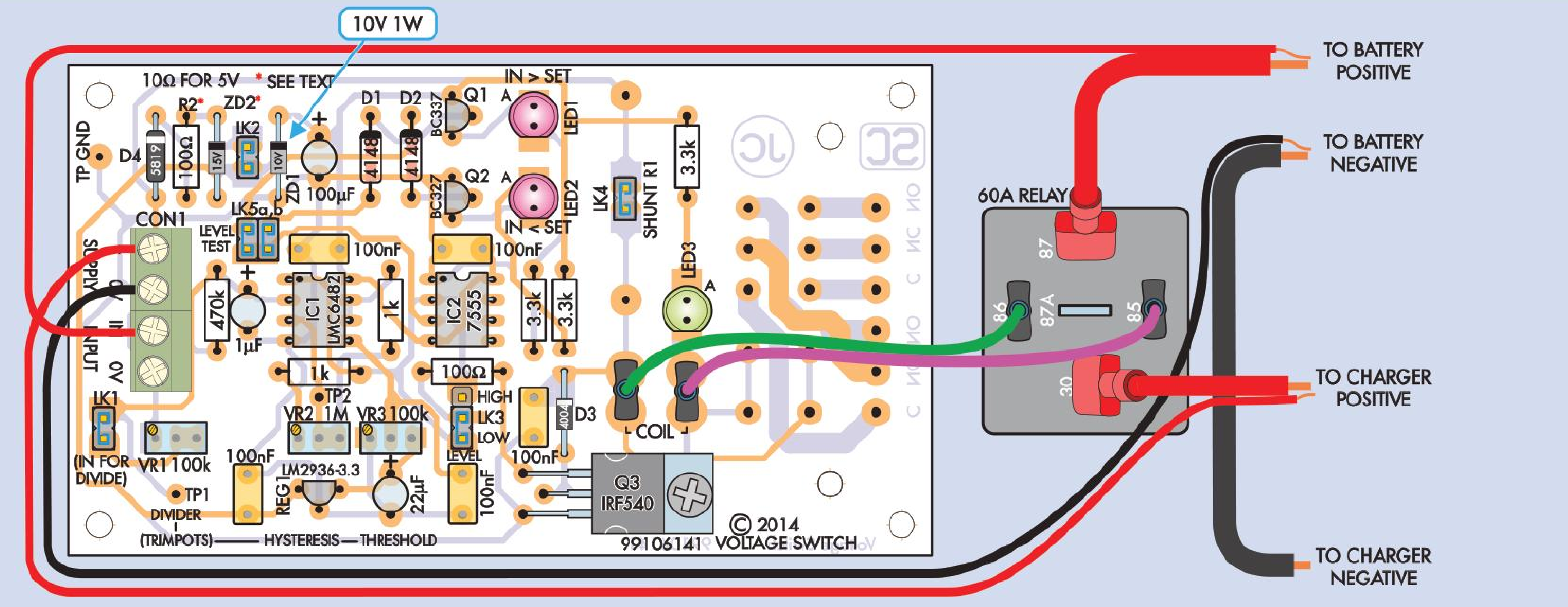

10V 1W
10Ω FOR 5V
* SEE TEXT
R2*
ZD2*
D1
D2
Q1
IN > SET
TP GND
D4
5819
100Ω
15V
LK2
10V
ZD1
100µF
4148
4148
BC337
BC327
Q2
LED1
LED2
IN < SET
LK4
SHUNT R1
3.3k
CON1
SUPPLY INPUT
0V
LEVEL TEST
LK5a,b
100nF
100nF
470k
1µF
IC1 LMC6482
1k
IC2 7555
3.3k
3.3k
LED3
A
1k
100Ω
TP2
VR2 1M
VR3 100k
HIGH
LK3
LOW
LEVEL
4004
D3
COIL
LK1
(IN FOR DIVIDE)
VR1 100k
100nF
LM2936-3.3
REG1
TP1
22µF
100nF
100nF
Q3 IRF540
DIVIDER (TRIMPOTS)
HYSTERESIS
THRESHOLD
© 2014
99106141 VOLTAGE SWITCH
60A RELAY
87
86
87A
85
30
TO BATTERY POSITIVE
TO BATTERY NEGATIVE
TO CHARGER POSITIVE
TO CHARGER NEGATIVE

Fig.6: follow this diagram to assemble the PCB and wire it to an external relay and battery charging circuit. Medium-duty hook-up wire can be used for all connections to the PCB, but be sure to use heavy-duty cable for all connections between the charger and the battery and to the relay contacts (30 and 87).

mounted externally, since it is too big to fit on the PCB.

It works like this: when the Common (COM) and normally open (NO) contacts are closed, the output from the charger is connected directly to the battery and the battery charges. As soon as the battery reaches 14.4V, the relay switches off and the contacts open, thereby disconnecting the battery to prevent overcharging.

The supply for the *TVS* comes from the charger (rather than the battery), so that the battery doesn't begin to discharge when charging ceases. We do, however, monitor the battery voltage, but this results in a current drain of less than 32µA. That's much less than the battery self-discharge current.

Note that the wiring to the *TVS* for voltage sensing is run separately from the battery terminals. This ensures that any voltage drop across the charging leads does not affect the measurement.

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The external leads exit through a cable gland at one end of the case and the leads for the battery are terminated in large alligator clamps. The two leads with the bared wire ends go to the battery charger.

Adding trickle charging

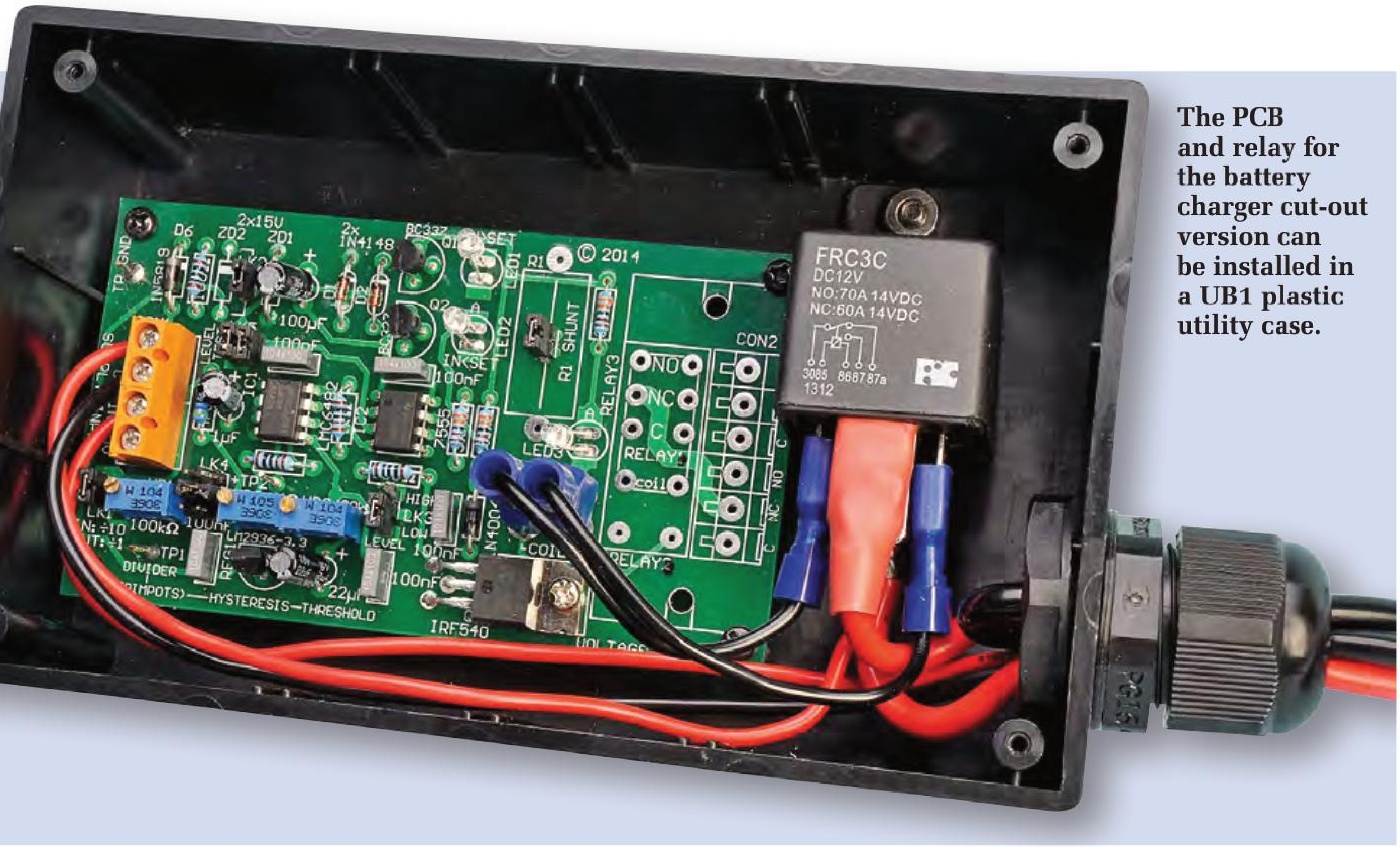
Switching to trickle charging at the end of a full charge is a good idea, since it ensures that the battery is always fully charged (without the risk of over-charging). The trickle charge must be low enough to allow the battery voltage to drop to below or be held at 13.8V.

Typically, the trickle current should be 0.025% of the battery's Ah capacity, or about 10mA for a 40Ah battery. This can be achieved by adding a 220Ω resistor across the relay contacts.

The resistor value is calculated assuming a charging voltage of 15.8V (ie, 2V more than the 13.8V battery voltage). A 220Ω resistor will dissipate less than 0.25W, but we recommend using a 1W resistor as it is more rugged and has thicker leads to make the connection to the relay terminals.

Fig.6 shows the PCB layout and external connections necessary to connect the TVS to the battery and the charger. The relay is mounted externally, with its coil terminated to the contacts on the PCB using spade quick connectors.

Note that Fig.6 shows the arrangement for charging a 12V battery. **Zener diode ZD1 is now a 10V 1W type (1N4740) instead of the original 15V Zener and provides a regulated 10V supply for comparator IC1a.** This regulated supply



The PCB and relay for the battery charger cut-out version can be installed in a UB1 plastic utility case.

is necessary because the hysteresis must be made quite wide and because supply variations would affect the voltage at which the *TVS* switches off charging.

For a 24V charger and battery, use another 10V 1W Zener diode for ZD2 and leave LK2 open. In addition, the 100Ω resistor (R1) needs to be changed to 220Ω 0.25W. You will also need a relay with contacts rated for 28V DC.

Medium-duty hook-up wire can be used for all connections to the *TVS*, but note that heavy duty cable must be used for all connections between the charger and the battery and for the connections to the relay contacts (30 and 87). We used 25A cable on our prototype, but you could use 10A cable if the charger is a low-current type rated at less than 5A.

As shown in the photos, we installed the PCB and relay in a UB1 plastic utility case measuring 158 × 95 × 53mm. The PCB mounts on M3 × 9mm tapped stand-offs and is held in place using M3 × 6mm screws. The relay is bolted to the base of the case using an M4 × 12mm screw and an M4 nut.

Finally, the connections to the relay contacts are all made via quick connectors and the external leads are fed through a 10-14mm cable gland at one end of the case.

Setting up the TVS

The *TVS* must now be set up for battery charging following this step-by-step procedure:

Step 1 Feed a voltage (9V) to the signal input on CON1, then accurately measure this voltage using a DMM (no need to apply power).

Step 2 Connect the DMM between TP1 and TP GND, make sure LK1 is installed and adjust VR1 for a reading that's one-tenth the measured voltage in Step 1. This sets VR1 to divide by 10.

Step 3 Measure the resistance between TP2 and the LOW position of LK3 (with the LK3 jumper out). Adjust VR2 for a reading of 90kΩ to set the hysteresis appropriately.

Step 4 Remove the input voltage, short the signal inputs on CON1 using a wire link and apply power to the circuit using the battery charger or a 12V supply.

Step 5 Monitor the voltage between TP2 and TP GND and adjust trimpot VR3 for 1.44V. This sets the *TVS* to disconnect the battery from the charger when it reaches 14.4V. The hysteresis setting ensures that the *TVS* will not switch the relay back on again to reconnect the charger until the input voltage falls below 12.6V.

Step 6 Remove the shorting link on the signal input and connect the signal '+' input to the positive supply rail instead. Now, with LK1 out, check the voltage between TP2 and TP GND; it should be close to 1.26V. TP2 should return to 1.44V if the signal input is again shorted to ground (ie, to 0V).

Step 7 Install LK3 in the LOW position. LK5a and LK5b can either be removed or left in circuit to show the charging status.

In practice, leaving LED1 and LED2 operating is a good idea because the relay indicator LED3 now glows even when the relay is off. This is due to the supply coming from the pulsating DC of the charger plus various capacitive effects which cause the LED to light. By contrast, with a normal constant DC supply, the relay LED is extinguished when the relay turns off.

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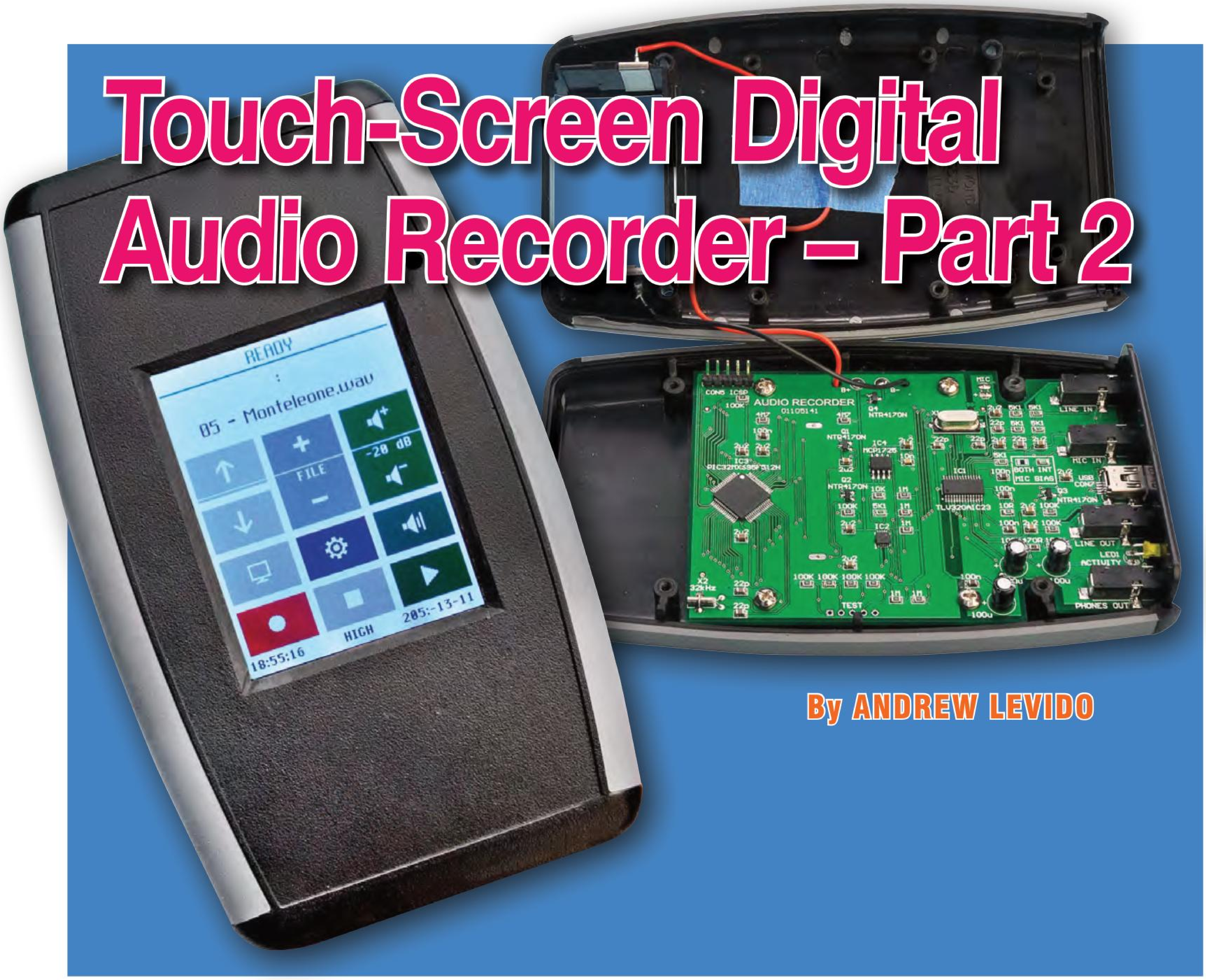
Touch-Screen Digital Audio Recorder – Part 2



By ANDREW LEVIDO

ALL THE PARTS for the *Touch-Screen Digital Audio Recorder* (except the battery) are mounted on a single PCB coded 01105141 (106 × 74mm) which is available from *EPE PCB Service*. Most of these parts and the connectors are surface-mount types, which are installed on the top side of the PCB. Only the microphone, touch-screen display and the SD card socket are located on the underside.

Don't be put off by the surface-mount nature of this project. With a little bit of care and patience, any reasonably experienced hobbyist can put this together in a few hours. As with any surface-mount work, you will need a good work light, fine tweezers, a flux pen and a roll of solder wick. If you have some form of magnification (or a magnifying lamp), then so much the better.

Fig.6 shows the parts layout on the PCB. Begin with IC2 (LM3658). This is a 10-pin QFN (quad flat no-lead) package with 0.5mm pin spacing and a central thermal pad. Once you have successfully soldered this device in (as described below), you can consider yourself an SMD guru!

The technique is as follows: start by applying a small amount of solder to each of the 10 outer pads on the PCB. You want just enough solder to later re-flow under the pins, but not so much that the pads are bridged or the chip does not sit flat against the board. Use solder wick to take off any excess if you have to.

Next, apply some liquid flux to the pads, then carefully position the chip so that it is centred horizontally and vertically with respect to the pads (take care to ensure that it is oriented correctly). Check that the pins, which are just visible on the sides of the chip, line up with the elongated pads. This is best done with the aid of a magnifying lens (or a microscope if you have access to one).

Once it's in place, hold the chip down using a pair of tweezers and apply your soldering iron to the elongated pads. Heat them just long enough for the solder you applied earlier to melt and re-flow under the pins. Add a small amount of solder during this procedure if necessary.

Once you have done this for all pins, flip the board over and melt a blob of solder into the four holes under the thermal pad. You will have to apply quite a bit of heat here, since the large rectangle of copper on the bottom side is designed to be a heatsink. This step will not only solder the thermal pad but will also continue the re-flow process for the pads.

Alternatively, if you are lucky enough to have a hot-air rework tool, simply apply a little solder paste to the pads, position the chip and re-flow the solder with the hot air. Surface tension will help pull the chip into position if your placement was not perfect. This is a lot faster and less prone to errors than using a soldering iron, so if you do a lot of SMT work it is an investment worth considering.

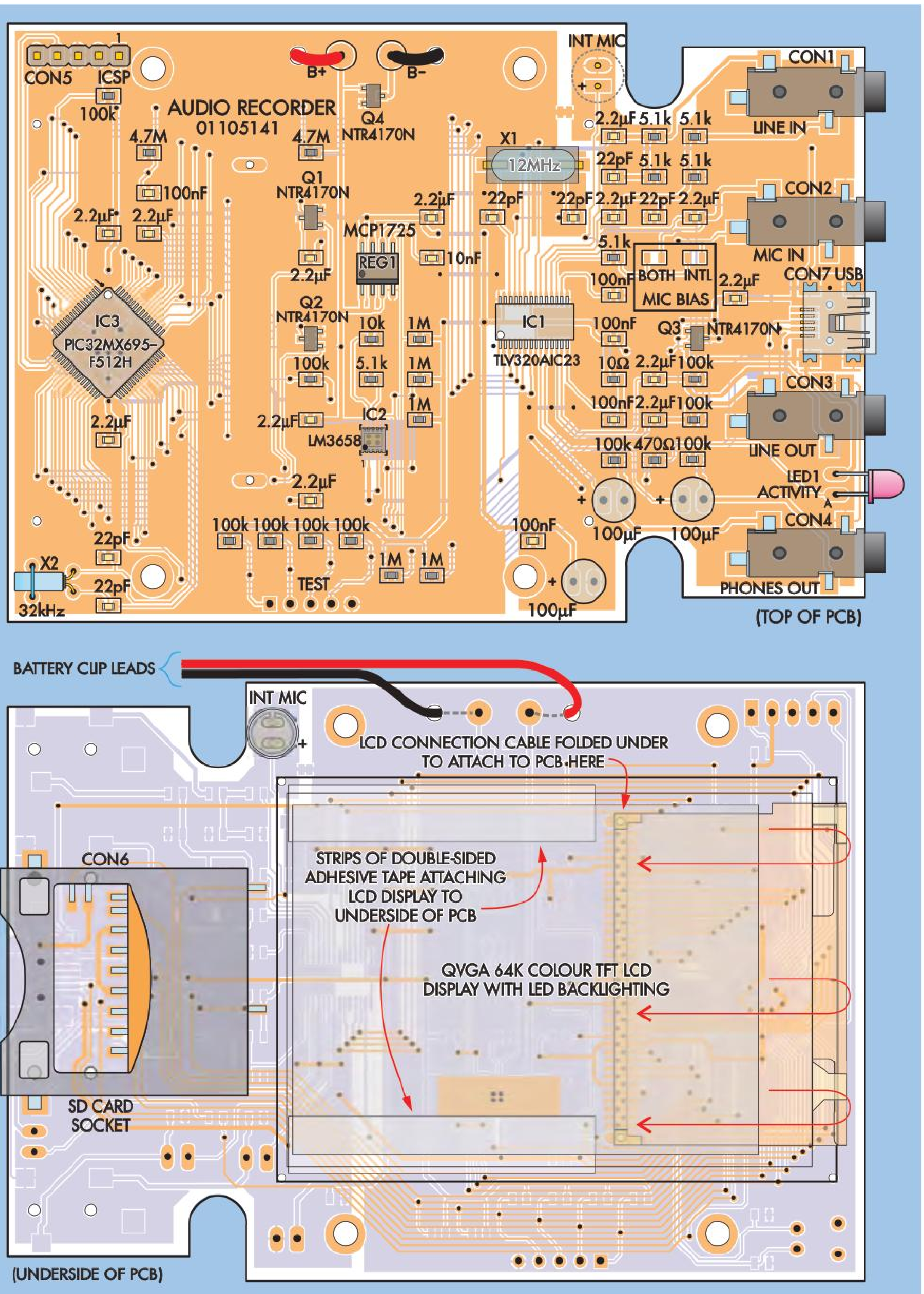
Note, however, that once the chip is in place, you still have to flip the PCB over and melt solder into the holes under the thermal pad.

Microcontroller IC3 is next on the list. Apply a generous amount of flux, then carefully position it on the pads (make sure it's correctly oriented) and tack solder a couple of pins on opposite corners. Now check that it's perfectly aligned and adjust if necessary before soldering the remaining pins.

Don't worry if you end up with a few solder bridges – you can clean these up later with solder wick.

The CODEC (IC1) can now be installed. With its 0.65mm pin spacing, it will seem positively huge compared to the last two chips. Use the same technique as for the microcontroller.

Regulator REG1 is the easiest of the lot. Once it's in, install the four SOT-23 MOSFETs and then the passive SMDs (ie, the resistors and capacitors). These are 0805 size and so are fairly straightforward to solder by hand. Take care here, because the capacitors are not marked and it's easy to mix them up.



CON5
ICSP
100k
AUDIO RECORDER
01105141
4.7M
4.7M
B+
B–
Q4
NTR4170N
INT MIC
X1
12MHz
CON1
LINE IN
CON2
MIC IN
CON7 USB
BOTH
INTL
MIC BIAS
Q1
NTR4170N
Q2
NTR4170N
Q3
NTR4170N
MCP1725
REG1
IC1
TLV320AIC23
IC2
LM3658
IC3
PIC32MX695-F512H
CON3
LINE OUT
LED1
ACTIVITY
A
CON4
PHONES OUT
X2
32kHz
TEST
(TOP OF PCB)
BATTERY CLIP LEADS
INT MIC
LCD CONNECTION CABLE FOLDED UNDER TO ATTACH TO PCB HERE
CON6
STRIPS OF DOUBLE-SIDED ADHESIVE TAPE ATTACHING LCD DISPLAY TO UNDERSIDE OF PCB
QVGA 64K COLOUR TFT LCD DISPLAY WITH LED BACKLIGHTING
SD CARD SOCKET
(UNDERSIDE OF PCB)

Fig.6: install the parts on the PCB as shown on these layout diagrams. The three SMD ICs and regulator REG1 go in first (see text), followed by the passive SMDs (resistors and capacitors) and then the larger through-hole parts. The LCD, SD card socket and internal microphone are mounted on the underside of the PCB, as shown in the bottom layout.

Microphone bias

You must now decide if you want the microphone bias to be available to the external microphone. If you do, install a link in the position marked 'BOTH' (near CON2); otherwise install a link in the position marked 'INTL'. You can either use a 0Ω (0805) resistor (as we have) or just bridge the pads with a blob of solder.

Next, install the USB connector (CON7). First, place it on the board (make sure that the locating pins go into their holes) and solder the four mounting tabs. You will have to apply a fair bit of heat to get the solder to take to these. It's then just a matter of soldering the five pins. These protrude just enough from the back of the connector to get at with a soldering iron.

Follow with the four 3.5mm audio jacks (CON1-CON4), then fit the through-hole electrolytic capacitors and the two crystals (X1 and X2). We used one of the capacitor lead offcuts to make a small strap to hold the 32kHz (X2) crystal in place.

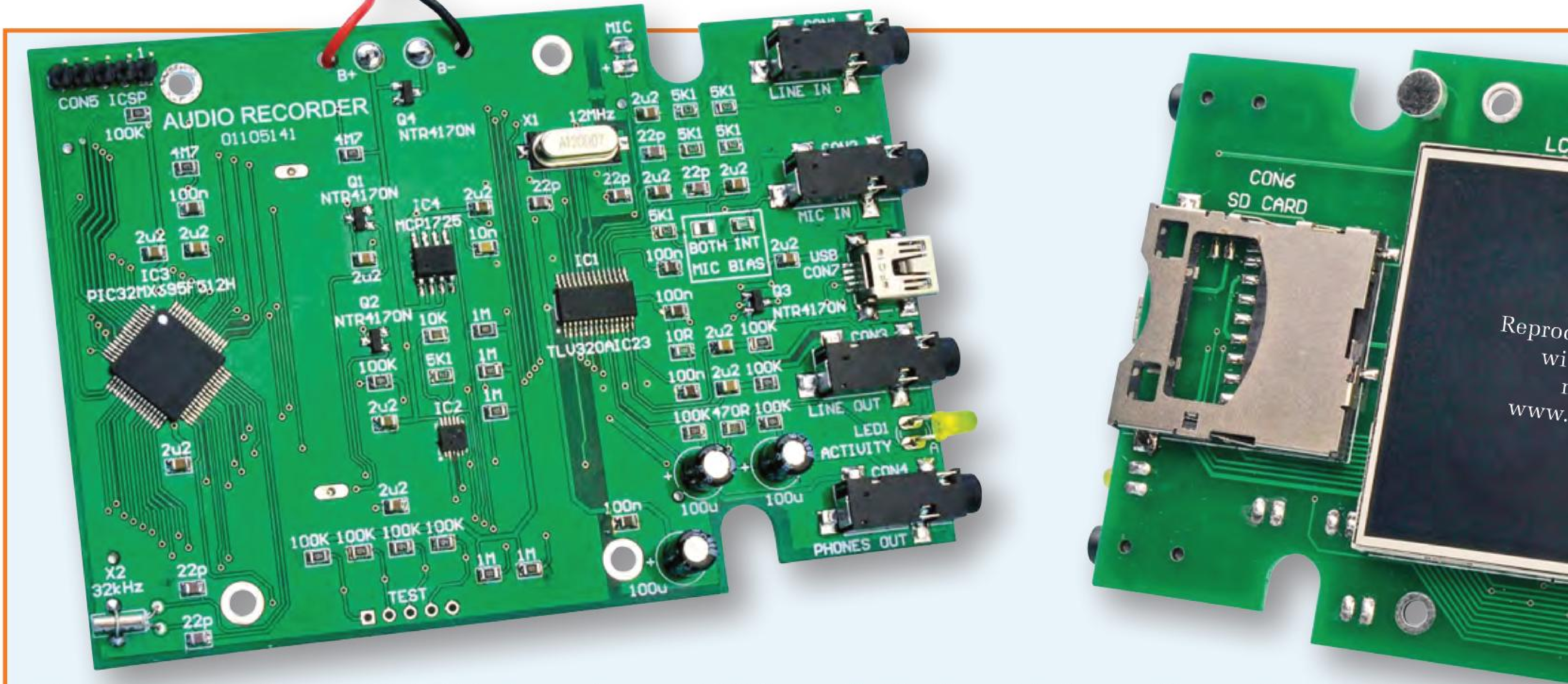
It's a good idea to also solder two more lead offcuts to the pads on the back of the electret microphone insert. This makes it easy to install later on.

The final step for this side of the board is to mount the ICSP header (CON5) if you intend to program the micro yourself. There's no need to mount the test header – it was used during development as a handy way to get access to the data traffic between the micro and the SD card.

SD card socket and LCD

As stated earlier, the SD card socket and the touch-screen LCD are mounted on the underside of the PCB (see Fig.6).

Start with the SD socket (CON6), as it's difficult to get to some of its pins once the LCD is installed. This socket shares its locating holes with two of

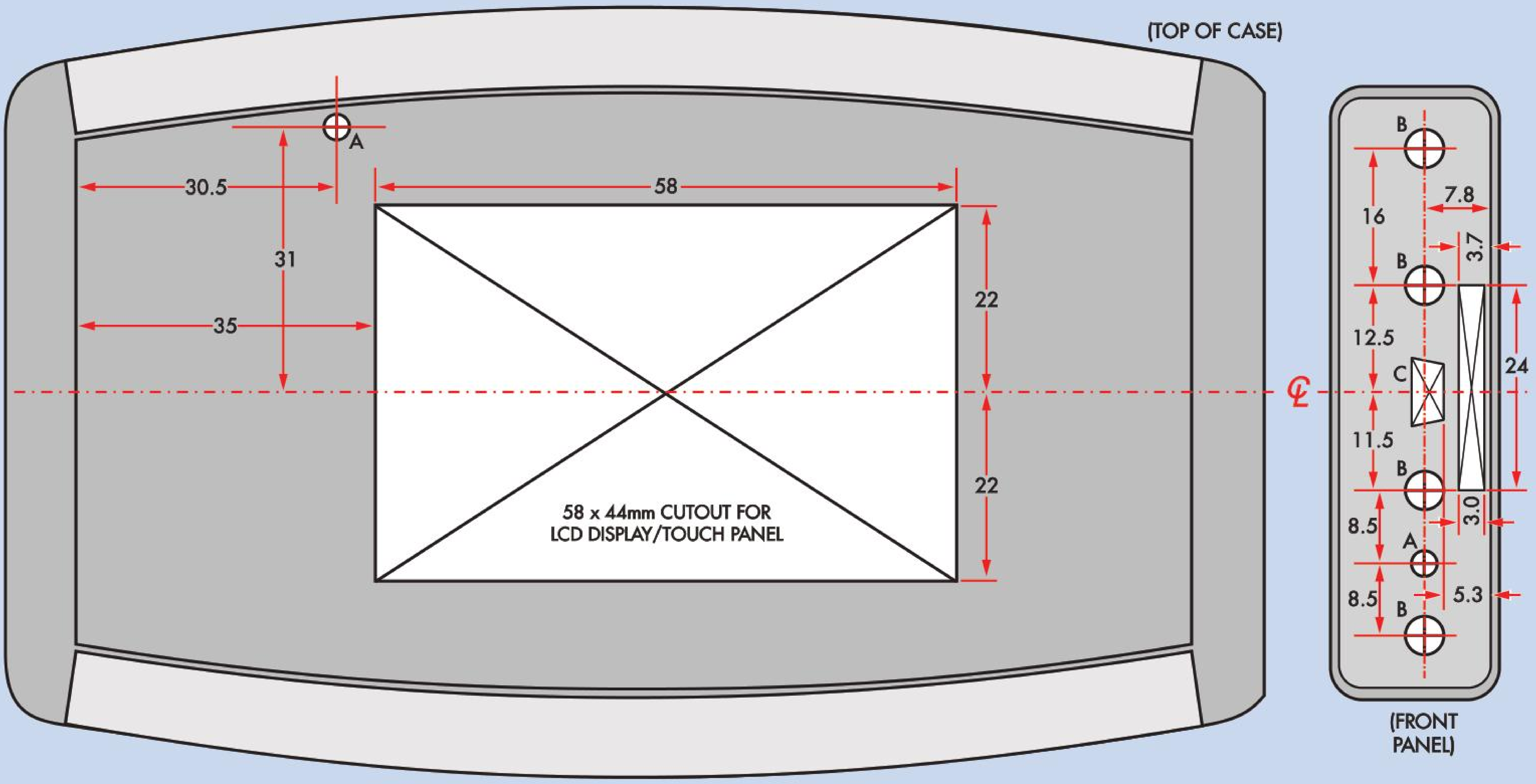

AUDIO RECORDER
01105141
CON5 ICSP
IC3
PIC32MX695F512H
Q1
NTR4170N
Q2
NTR4170N
Q3
NTR4170N
Q4
NTR4170N
IC4
MCP1725
IC1
TLV320AIC23
IC2
X1
12MHz
X2
32kHz
MIC
B+
B-
LINE IN
MIC IN
USB
CON7
BOTH INT
MIC BIAS
LINE OUT
LED1
ACTIVITY
PHONES OUT
TEST
CON6
SD CARD

These views show the assembled PCB. The touch-screen LCD is installed by first soldering its ribbon cable to its PCB pads, then folding the LCD over this cable and securing it using strips of double-sided adhesive tape (see Fig.6).

the audio jacks. There are four pads to solder around the outside and 11 on the inside.

Mounting the LCD involves soldering its flexible ribbon cable to corresponding pads on the underside of the PCB. The two 1mm holes at either edge of the ribbon are used to line everything up. Take a minute or two to familiarise yourself with the correct orientation of the display before soldering any pads; it should be positioned such that it can fold back over the ribbon cable to face up as shown in Fig.6.

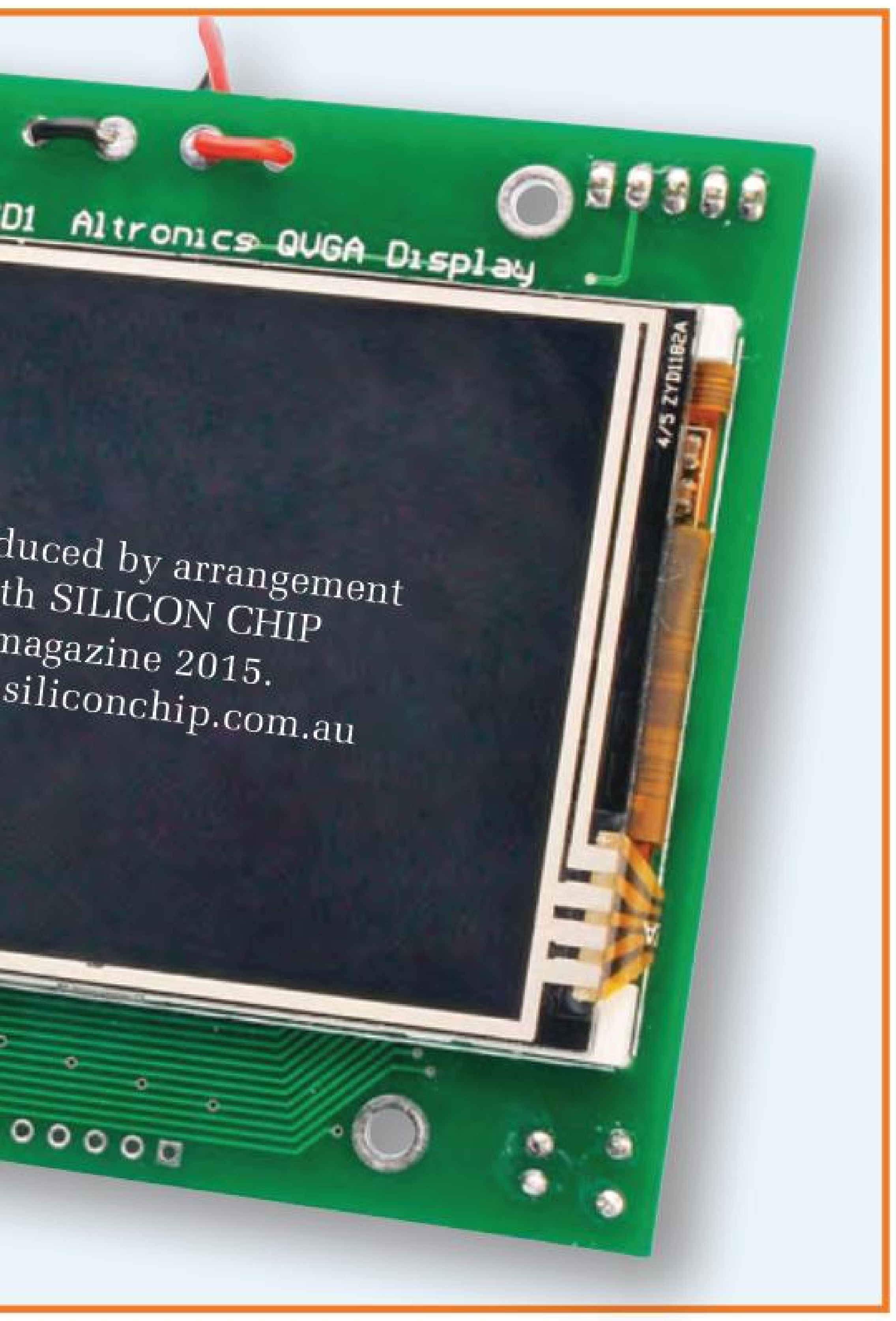
To install it, first peel the cover paper off the strip of double-sided sticky tape on the ribbon (not the strips on the back of the display). That done, line up the two 1mm holes in the ribbon with their corresponding holes in the PCB (we used a couple of 1mm drill bits to make this easy), then press down on the ribbon to fix it onto the PCB with the tape.


(TOP OF CASE)
A
30.5
58
31
35
22
22
58 x 44mm CUTOUT FOR
LCD DISPLAY/TOUCH PANEL
℄
B
16
7.8
3.7
B
12.5
24
C
11.5
B
3.0
8.5
A
8.5
5.3
B
(FRONT
PANEL)

HOLES A: 3.0mm DIA. HOLES B: 4.5mm DIA. HOLE C: 3.75mm x 8.0/6.5mm

ALL DIMENSIONS IN MILLIMETRES

Fig.7: follow this diagram to make the display cutout in the case lid and to drill and cut the holes in the end panel. The display cutout can be made by drilling a series of holes around the inside perimeter, knocking out the centre piece and filing the job to a smooth finish. Hole 'A' at top left is for the microphone.



Parts List

- 1 double-sided PCB, available from *EPE PCB Service*, code 01105141, 106 × 74mm
- 1 black hand-held ABS case with battery compartment, 89 × 147 × 25mm (Altronics H8986)
- 1 12MHz HC-49/US SMD crystal (X1) (Altronics V2267, element14 1842280, Digi-Key 535-10218-1-ND)
- 1 32.768kHz watch crystal (X2)
- 1 3mm orange or red LED (LED1)
- 1 QVGA RGB LCD touch-screen with LED back-light and controller (Altronics Z7080)
- 4 3.5mm switched SMD stereo jack sockets (CON1-CON4) (Digi-Key CP-3524SJCT-ND)
- 1 5-pin header (CON5) (optional, for in-circuit programming)
- 1 push-push SD card socket (CON6) (Altronics P5720 or equivalent)
- 1 SMD mini-B type USB connector (CON7) (Altronics P1308, element14 1507528, Digi-Key 151-1206-1-ND)
- 1 electret microphone insert (MIC1)
- 4 No.4 × 6mm self-tapping screws
- 1 short length light-duty red hook-up wire
- 1 short length light-duty black hook-up wire
- 1 3.6V lithium-ion AA cell
- 1 AA cell-sized piece of non-conductive foam
- 1 SD/SDHC/SDXC card
- 1 USB type A to mini type B cable
- 1 short length double-sided tape

Semiconductors
- 1 TLV320AIC23 96kHz audio CODEC IC (IC1) (element14 1575048, Digi-Key 296-26817-1-ND)
- 1 LM3658SD Li-ion battery charger IC (IC2) (element14 1312584 or Digi-Key LM3658SD/NOPBCT-ND)
- 1 PIC32MX695F512H SMD microcontroller programmed with 0110514B.hex (IC3)
- 1 MCP1725-3002E/SN LDO 3.0V regulator (REG1) (element14 1851958 or Digi-Key MCP1725-3002E/SN-ND)
- 4 NTR4170N SMD N-channel SOT-23 MOSFETs (Q1-Q4) (element14 1887064 or Digi-Key NTR4170NT1GOSCT-ND)

Capacitors (all SMD 2012 size [0805 imperial] unless specified)
- 3 100µF 6.3V electrolytic
- 13 2.2µF 16V X7R ceramic
- 5 100nF 50V X7R ceramic
- 1 10nF 50V X7R ceramic
- 6 22pF 50V C0G/NP0 ceramic

Resistors (all SMD 2012 size [0805 imperial])

2 4.7MΩ	6 5.1kΩ
5 1MΩ	1 470Ω
10 100kΩ	1 10Ω
1 10kΩ	1 0Ω

Altronics offer a kit for about £75 incl p&p (Cat. K5530). SMD IC1-IC3 are pre-soldered to PCB, See: www.altronics.com.au/p/k5530-touchscreen-digital-audio-recording-kit/

The ribbon cable can now be soldered to the pads. Work quickly here, as the ribbon will melt if you apply too much heat. We found it best to press the ribbon down onto the PCB with a probe, then solder three or four pads at a time, moving progressively along the ribbon.

Once the soldering is complete, fold the display over the ribbon and secure it to the PCB using the two strips of double-sided adhesive tape on the back of the panel. During this process, make sure that the LCD panel's four plastic posts (one at each corner) drop into their locating holes in the PCB.

Now fit the electret microphone insert (ie, with the wire leads soldered to it) to the PCB, observing the polarity. Don't solder it yet though; instead, position the PCB in the top half of the case and temporarily fix it there with a couple of mounting screws. That done, push the microphone down until its face is flush with the inside of the case, then solder its leads and trim off any excess.

The PCB assembly can now be completed by soldering the battery clip leads to the battery terminals (marked B+ and B–). Be sure to loop these leads through the strain relief holes, as shown in Fig.6.

Preparing the case

Now turn your attention to the case. First, carefully mark out the LCD cutout and the microphone hole on the lid, as shown in Fig.7. That done, cut out the rectangular hole for the LCD and clean up the edges using a fine file. We chamfered the edges of the cut-out to improve its appearance, as shown in the photos of the unit.

Next, drill the 3mm-diameter hole for the microphone, then mark out and drill the end panel, as shown in Fig.7. Alternatively, you can simply attach the end-panel diagram to the panel and use it as a drilling template.

The cut-outs for the USB socket and the SD card socket can be made by drilling a series of very small holes, joining them up and then filing the job to shape. Once completed, test fit the panel to the PCB – you may need to fettle the socket openings to get everything to line up nicely.

Be careful when drilling and cutting out this end panel. There are a lot of connectors in a very small space, so there is almost 'more hole' than panel.

Once everything is correct, fit the front panel to the PCB and then insert the assembly into the top section of the case. Secure the board with four short self-tapping screws, then fit two of the supplied battery terminals into the bottom half of the case. Solder the battery wires to these terminals, making sure that the positive lead goes to the positive terminal and the negative lead goes to the (spring-loaded) negative terminal.

We used a piece of foam to fill the open space in the left-over battery position, so the cell cannot move.

Testing and troubleshooting

Now for the smoke test! The step-by-step procedure is as follows:

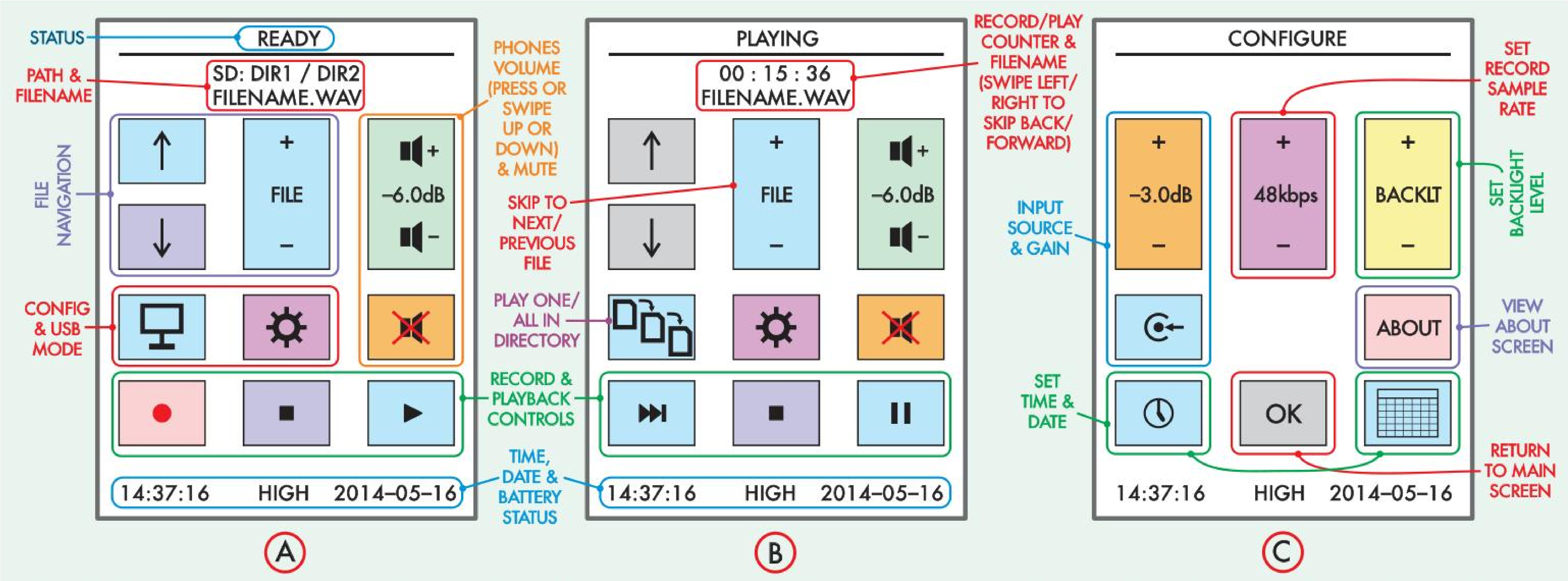

STATUS
READY
PATH & FILENAME
SD: DIR1 / DIR2
FILENAME.WAV
FILE NAVIGATION
FILE
−6.0dB
PHONES VOLUME (PRESS OR SWIPE UP OR DOWN) & MUTE
CONFIG & USB MODE
RECORD & PLAYBACK CONTROLS
TIME, DATE & BATTERY STATUS
14:37:16 HIGH 2014–05–16
PLAYING
00 : 15 : 36
FILENAME.WAV
RECORD/PLAY COUNTER & FILENAME (SWIPE LEFT/ RIGHT TO SKIP BACK/ FORWARD)
SKIP TO NEXT/ PREVIOUS FILE
PLAY ONE/ ALL IN DIRECTORY
CONFIGURE
INPUT SOURCE & GAIN
−3.0dB
48kbps
BACKLT
SET RECORD SAMPLE RATE
SET BACKLIGHT LEVEL
ABOUT
VIEW ABOUT SCREEN
SET TIME & DATE
OK
RETURN TO MAIN SCREEN
A
B
C

Fig.8: the icons (or buttons) displayed on the touch-screen LCD are context sensitive and may be greyed out if not relevant to the current function. There are three main status screens: READY, PLAYING and CONFIGURE.

1) Connect a bench power supply set to deliver 4V to the battery terminals (ie, without the battery installed). Be sure to get the polarity correct and if your supply has current limiting, set this to around 500mA.
2) Apply power and check that the LCD lights up and displays the various menus and icons. Of course, this assumes that you purchased a pre-programmed micro. If the micro didn't come pre-programmed, now is the time to program it.
3) Once you have a working micro, insert an SD card and check that you can move through the directories, play audio files and make a recording using the internal microphone.
4) If that checks out, remove the power supply, insert a battery and check that it begins to charge when the unit is connected to a USB port on a PC.
5) Press the USB button and verify that the audio recorder appears as an external drive on the PC.

If this all checks out, you are ready to start using the *Touch-Screen Digital Audio Recorder*. If you do have problems, work logically to isolate the cause. If the display is black, for example, check the 3V rail and 12MHz clock to make sure these are OK, since the micro can't run without them.

If the 32kHz oscillator is working, then you can be sure the micro itself is OK, so look for problems with MOSFETs Q1 and Q2 and for soldering issues on the LCD ribbon cable and the corresponding pins on the micro.

If the display works, but you can't read an SD card, check the components and soldering in that part of the circuit. Make sure that the SD card is formatted correctly and try an alternative card if there are still problems. Similarly, if there is a problem with the audio, check the circuitry around IC1.

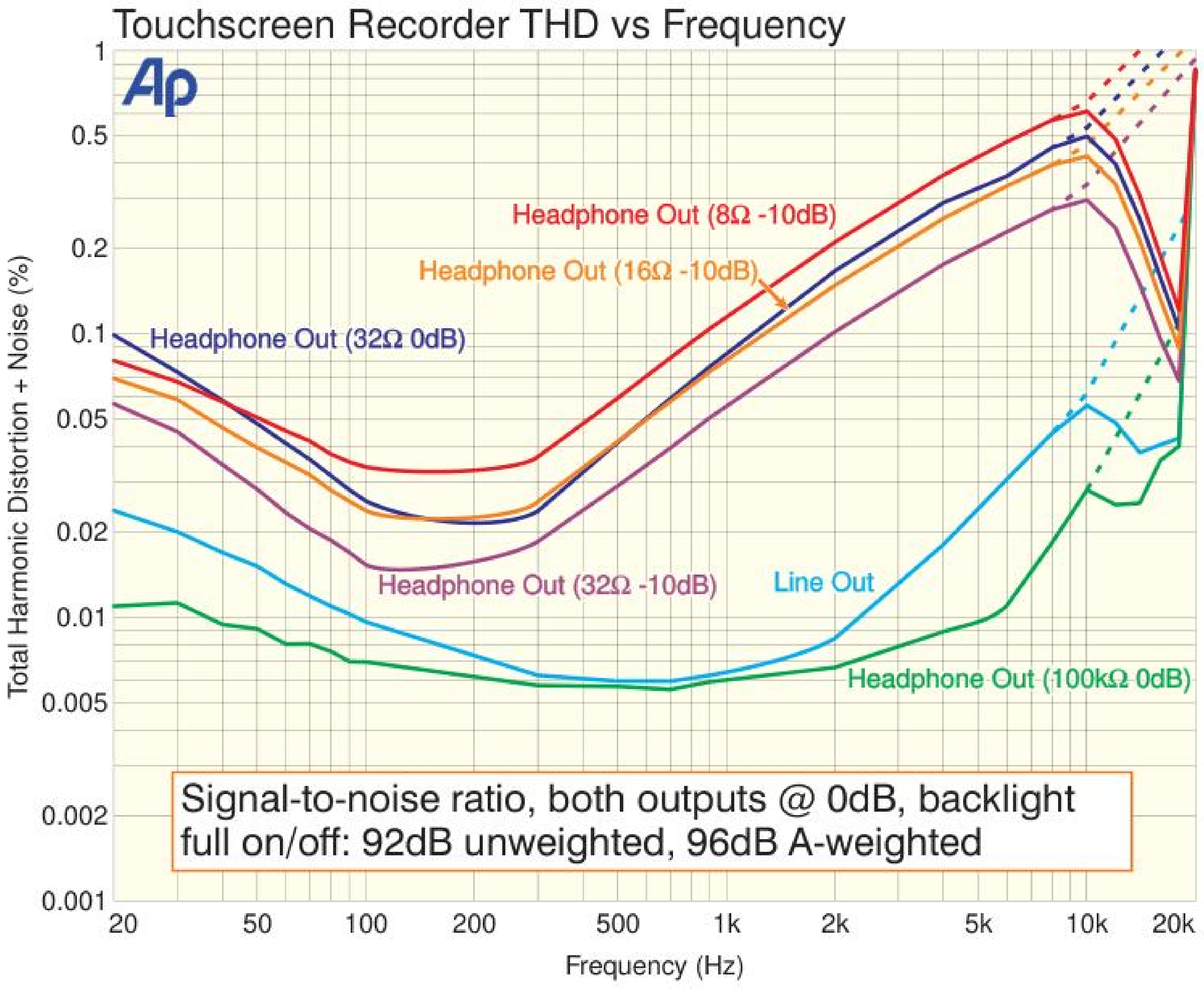


Fig.9: distortion vs frequency plots for the recorder. Note that since the headphone output performance (at 0dB) into a high impedance is better than the line output, there's little reason to use the line output. We had to use a 20kHz low-pass filter for these measurements so distortion above 10kHz is understated; the dotted lines indicate our guess as to the real performance.

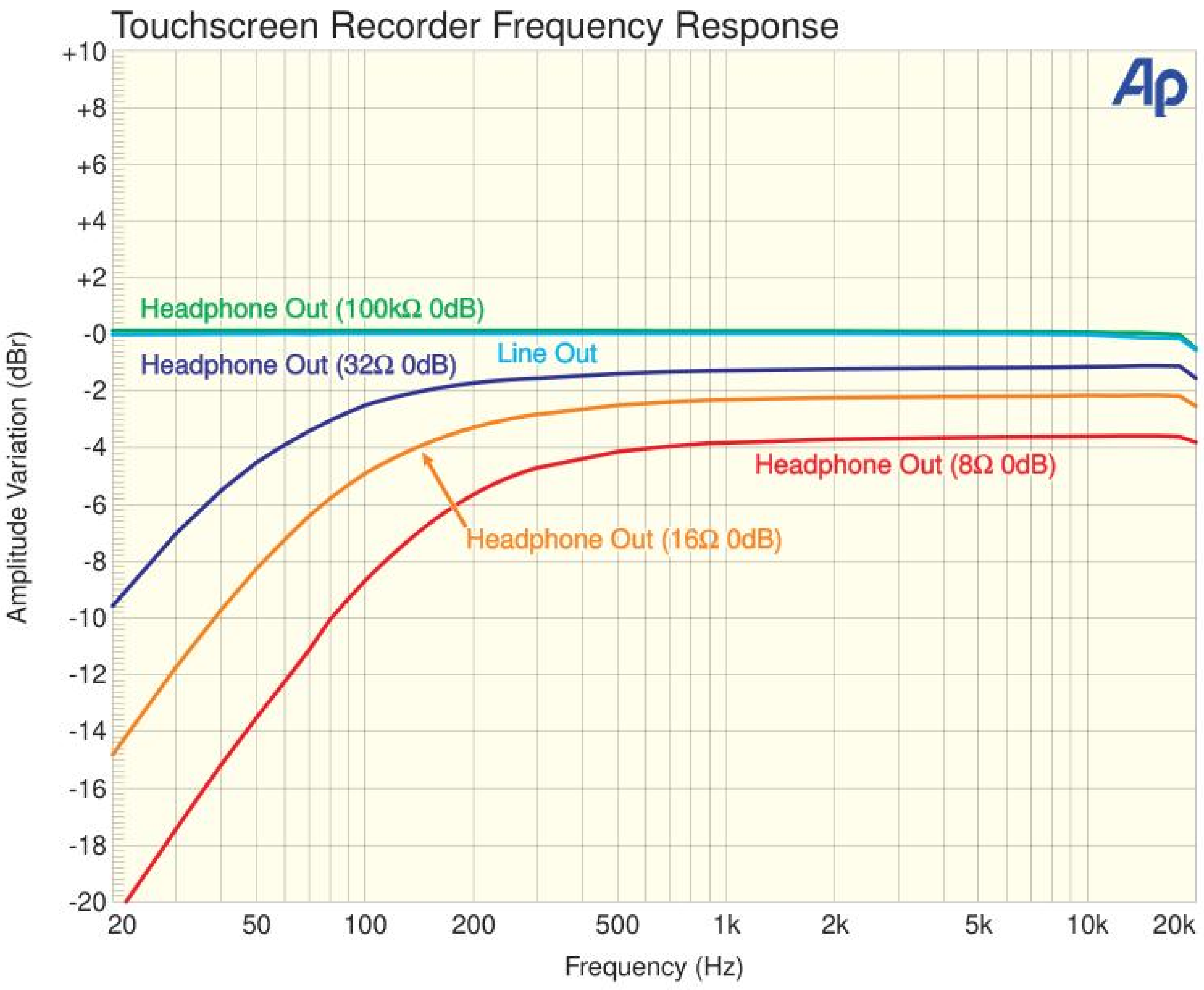


Fig.10: the frequency response is flat for either output up to 18kHz into a high-impedance load. However, the low-frequency roll-off is significant when driving headphones (typical 16Ω headphones/ear-buds have a –3dB point of 100Hz). Note that bass performance could be improved by increasing the value of the two 100µF electrolytic coupling capacitors to 470µF.

If the activity LED pulses steadily while playing and recording, you can be reasonably sure that the problem lies with the CODEC or its surrounding circuitry. Any problems are most likely to be caused by incorrectly positioned parts, solder bridges or missed/faulty solder joints.

Using the recorder

The Touch-Screen Digital Audio Recorder is fairly intuitive to use. Most of the time, the user interacts with a single screen like that shown in Fig.8A. The 'buttons' are context sensitive and may be greyed out if they are not relevant for some reason. For example, as shown in Fig.8A, the 'Stop' button will be greyed if there is nothing playing or recording.

A status bar is shown at the top of the screen and immediately below that are two lines of text (eg, to indicate the directory path and filename). In addition, the current time and date are displayed at the bottom of the screen, along with the battery charge/discharge status.

The READY status in Fig.8A indicates that an SD card has been successfully mounted. The file navigation keys can then be used to move through the directories and files on the card. The file 'rocker' moves through the entries in the current directory.

The current entry (eg, a filename) is displayed on the lower of the two text lines and the path is shown on the upper line. If the current entry is a directory, the down arrow allows a sub-directory to be selected. Similarly, the up arrow button allows you to move up to the parent directory, if you are currently below the root directory.

Immediately below the file navigation area are buttons to jump to the configuration screen and to put the recorder into USB mode. MSD mode allows the files on the recorder to be read on a PC via the USB port. To the right of this are the headphone volume control and the output mute button.

The bottom row of buttons controls the record and playback functions. Pressing the Record button creates a new file and begins a recording, while pressing the Play button opens and plays the selected file. Once playing, the screen changes slightly to that shown in Fig.8B (the record screen is similar).

At the same time, the status changes to PLAYING and a counter replaces the path name. In addition, the file navigation and USB mode buttons are disabled and the play/record controls change as shown.

The action of the Pause button is fairly obvious – it toggles between pause and resume on alternate presses. The Skip button stops playing the current file and skips to the next one in the directory. When recording, the Skip button closes the current file and immediately opens another and carries on recording into that.

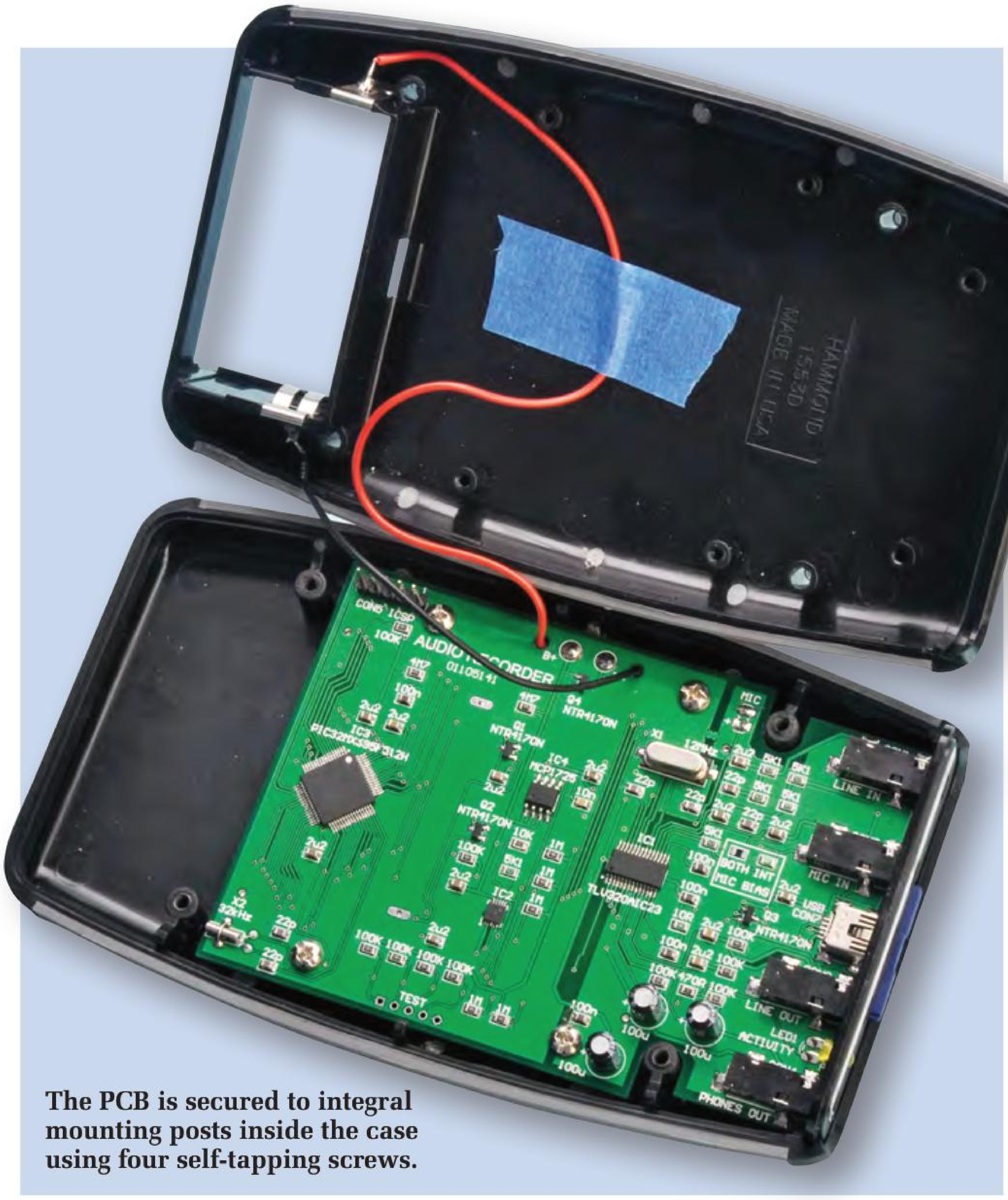
Fig.8C shows the configuration screen. It's entered by pressing the Configuration button on the main screen. At the top left is the line input gain rocker, while immediately below that is the input source selector. Pressing this repeatedly rolls through the three options: line input, mic input and mic input with 20dB extra gain.

At top centre is the record sample rate selector and to its right, the backlight level control. Any change to the sample rate applies from the next recording. The About button displays the software version information (as you might expect) while the OK button returns control to the main screen.

Either side of the OK button are buttons that allow setting of the time and date. If an error occurs at any time, a message is displayed at the top of the screen along with an Acknowledge button to dismiss it. The error message gives the reason for the error and a code indicating which part of the software was responsible.

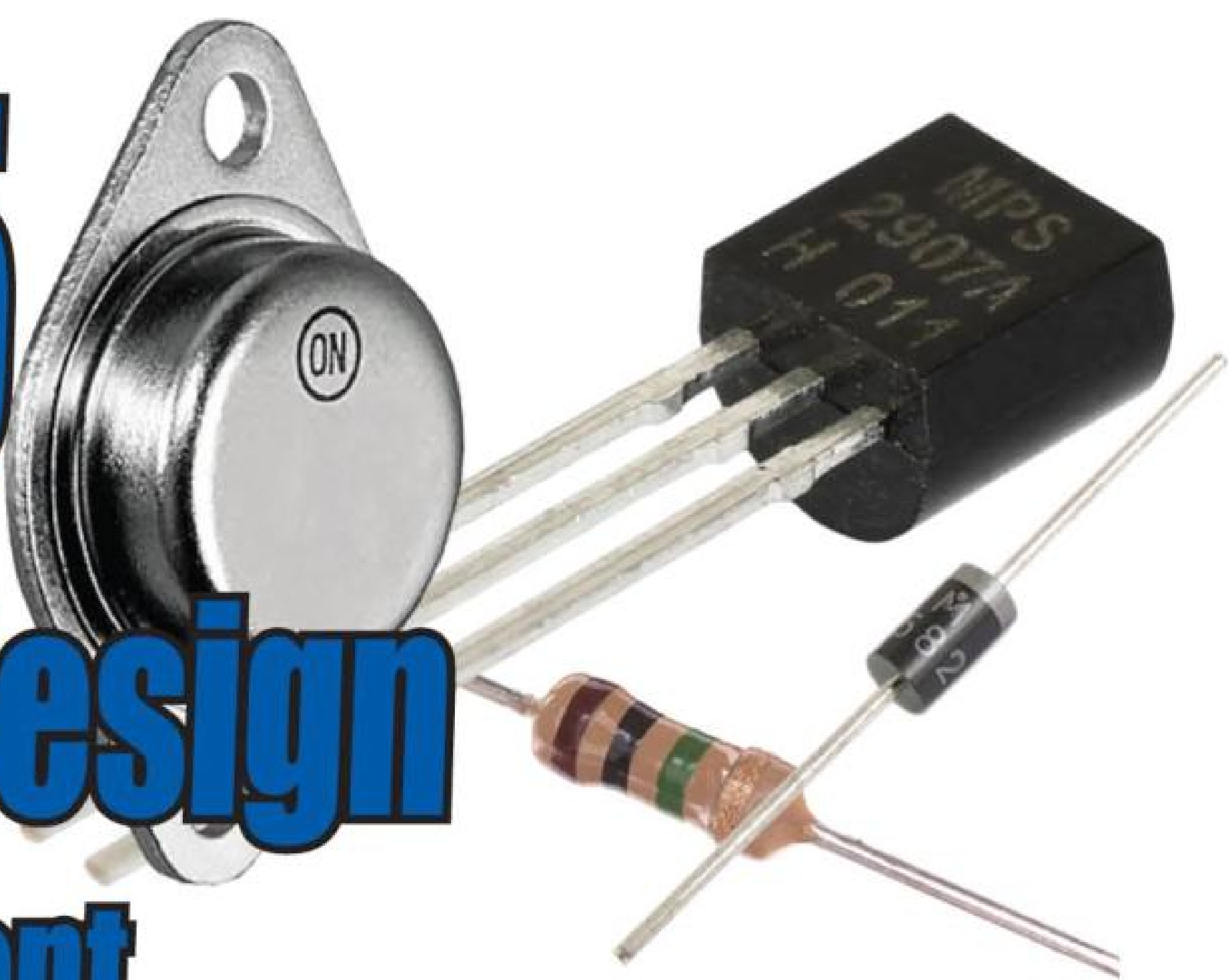
If a catastrophic error occurs, the activity LED will flash an error code. These error codes correspond to the processor exception codes – except for a double flash that indicates the event queue has overflowed. These errors should never happen under normal circumstances and a full reset is the only way to recover.

You can explore the rest of the user interface yourself and even attempt some software modifications of your own if you are so inclined.



The PCB is secured to integral mounting posts inside the case using four self-tapping screws.

Teach-In 2015



Discrete Linear Circuit Design

Part 6: Power and power measurement

by Mike and Richard Tooley

Welcome to *Teach-In 2015.* This series is aimed at anyone wishing to develop a detailed understanding of linear discrete semiconductor devices and how they are used in a diverse range of circuits. We hope you will join us on this exciting voyage of discovery! Each part of our *Teach-In 2015* series is devoted to a different aspect of discrete linear circuit design such as modelling and simulation, measurement and testing, noise and distortion. In last month's instalment, *Knowledge Base* introduced the use of filters to modify or correct the frequency response of an amplifier or audio system, while *Discover* took a detailed look at noise and how it can be measured and reduced. Our regular practical feature, *Get Real*, described the design and construction of a versatile tone control stage that can be used on its own or in conjunction with the other projects featured in our *Teach-In 2015* series.

Introduction

In this month's *Get Real* we will show you how we used our favourite software applications to check the operation of the simple tone control prior to its construction and also how we measured the performance of our final prototype design. We then reveal whether we managed to achieve our original design objectives! *Discover* is devoted to power and power measurement, while *Knowledge Base* will introduce you to two useful circuit building blocks in the form of constant current and constant voltage sources.

Discover: Power and power measurement

Frequently used terms such as 'peak music power' (PMP) and 'peak momentary power output' (PMPO) can be very misleading and are, sadly, all too often used to bamboozle would be purchasers of cheap audio equipment. A classic but seriously flawed example of this is the school of thought that suggests PMPO can be determined simply by multiplying an amplifier's supply voltage by the value of short-circuit current that it can produce (if only for an instant before the fuse blows or the over-current protection operates). This measure is badly flawed because it assumes that the amplifier has been designed so that it survives such a condition (invariably, it won't) and that the short-circuit condition only lasts for a very short time. Usually, no specific time is quoted, so it could be as brief as a few nanoseconds before your amplifier goes up in smoke!

Specifying output power

Ideally, the power that an amplifier can deliver should never be time limited. In other words, it should be the power that the amplifier can deliver continuously and should be the product of voltage and current in the load connected to an amplifier when operated under true sinusoidal conditions. This power is sometimes referred to as 'RMS power' since the values of voltage and current measured are both expressed in terms of 'root mean square' values. These are the values that would be indicated on a meter calibrated for sinewave operation (as is invariably the case with instruments that are designed to make conventional AC power line measurements). The term 'RMS power' is, however, somewhat misleading since the power that is indicated by this measurement is actually the *average* power over a cycle of the wave, and when this power is dissipated in a resistor it appears as heat. To put it bluntly, the often-quoted term 'RMS watts' is just as meaningless as the term 'peak watts'!

To put this into context, let's assume that you have a load of known resistance (not a loudspeaker) connected to an amplifier and that the amplifier is supplied with a sinewave signal source within the middle of the audio band (usually 1kHz). We also need to ensure that the output of the amplifier (the voltage or current that we are going to measure) is not distorted (ie, it is truly sinusoidal). In order to do this we would need to observe the output waveform, checking, in particular, that it has not become clipped or otherwise distorted. If we now measure the RMS AC voltage we can determine the output power, P_{out}:

$$P_{out} = I_{out} \times V_{out} = \left(\frac{V_{out}}{R_L}\right) \times V_{out} = \frac{V^2_{out}}{R_L}$$

If, for example, we had used an 8Ω load and measured an undistorted 6V RMS developed across it, we would be able to determine the power output:

$$P_{out} = \frac{V^2_{out}}{R_L} = \frac{6^2}{8} = \frac{36}{8} = 4.5\text{W}$$

If we had used an oscilloscope (instead of an AC meter) to measure the output voltage we would probably find it much easier to measure the peak-to-peak value of the waveform. We can then convert this value, $V_{out(pk-pk)}$, to an RMS value and use that value in our calculation, as follows:

$$P_{out} = \frac{V^2_{out}}{R_L} = \frac{\left(\dfrac{V_{out(pk-pk)}}{2\sqrt{2}}\right)^2}{R_L} = \frac{V_{out(pk-pk)}{}^2}{8R_L}$$

Putting this into context with some typical figures, let's assume that the oscilloscope indicates a peak-peak voltage of 12V with a load having a resistance of 15Ω. The output power would be:

$$P_{out} = \frac{V_{out(pk-pk)}{}^2}{8R_L} = \frac{12^2}{8 \times 15} = \frac{144}{120} = 1.2\text{W}$$

Continuous average power

The term 'continuous average power' was first introduced in the US and several other countries as a means of dispelling some of the myths associated

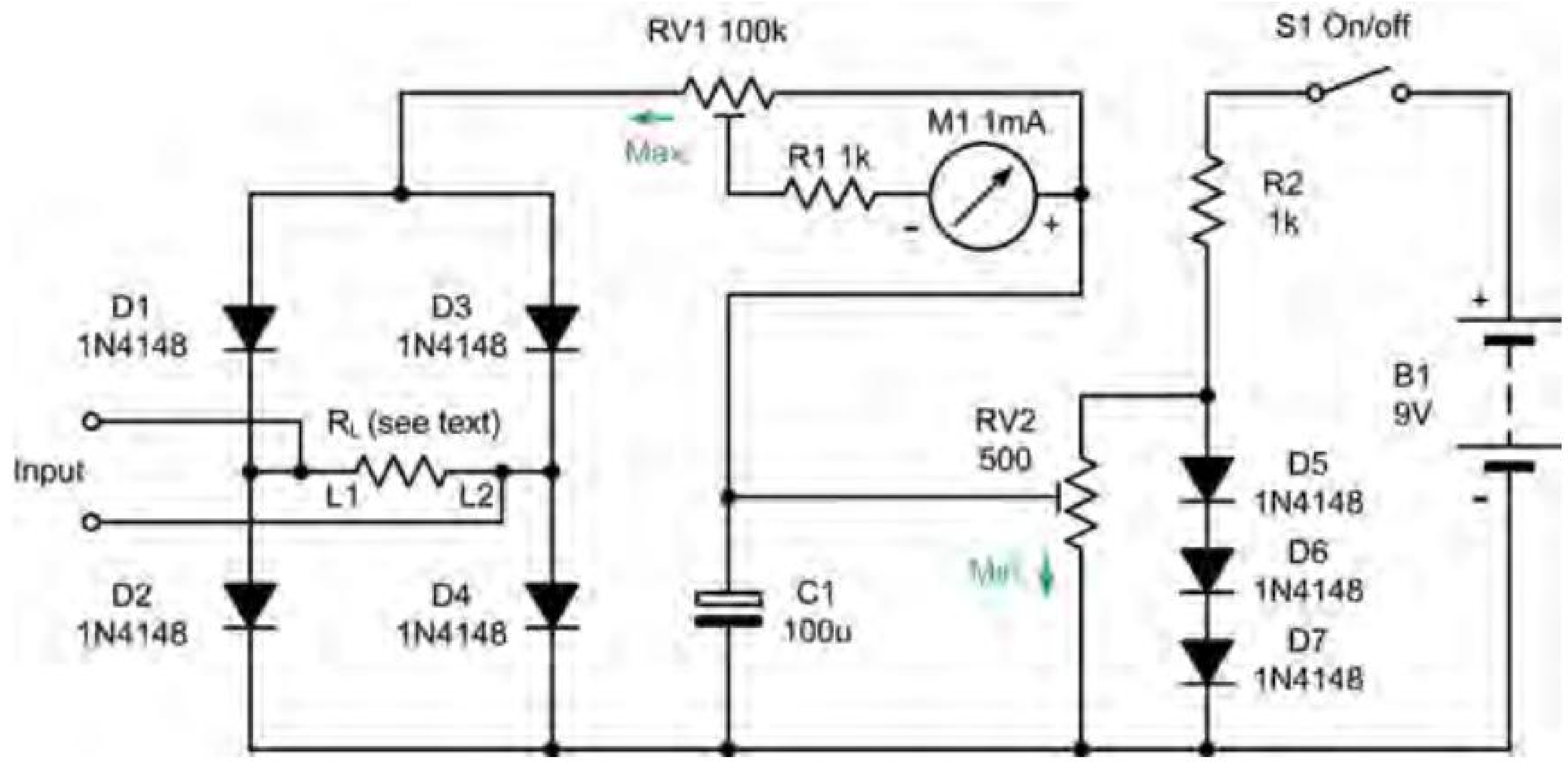


Fig.6.1. The indicating module

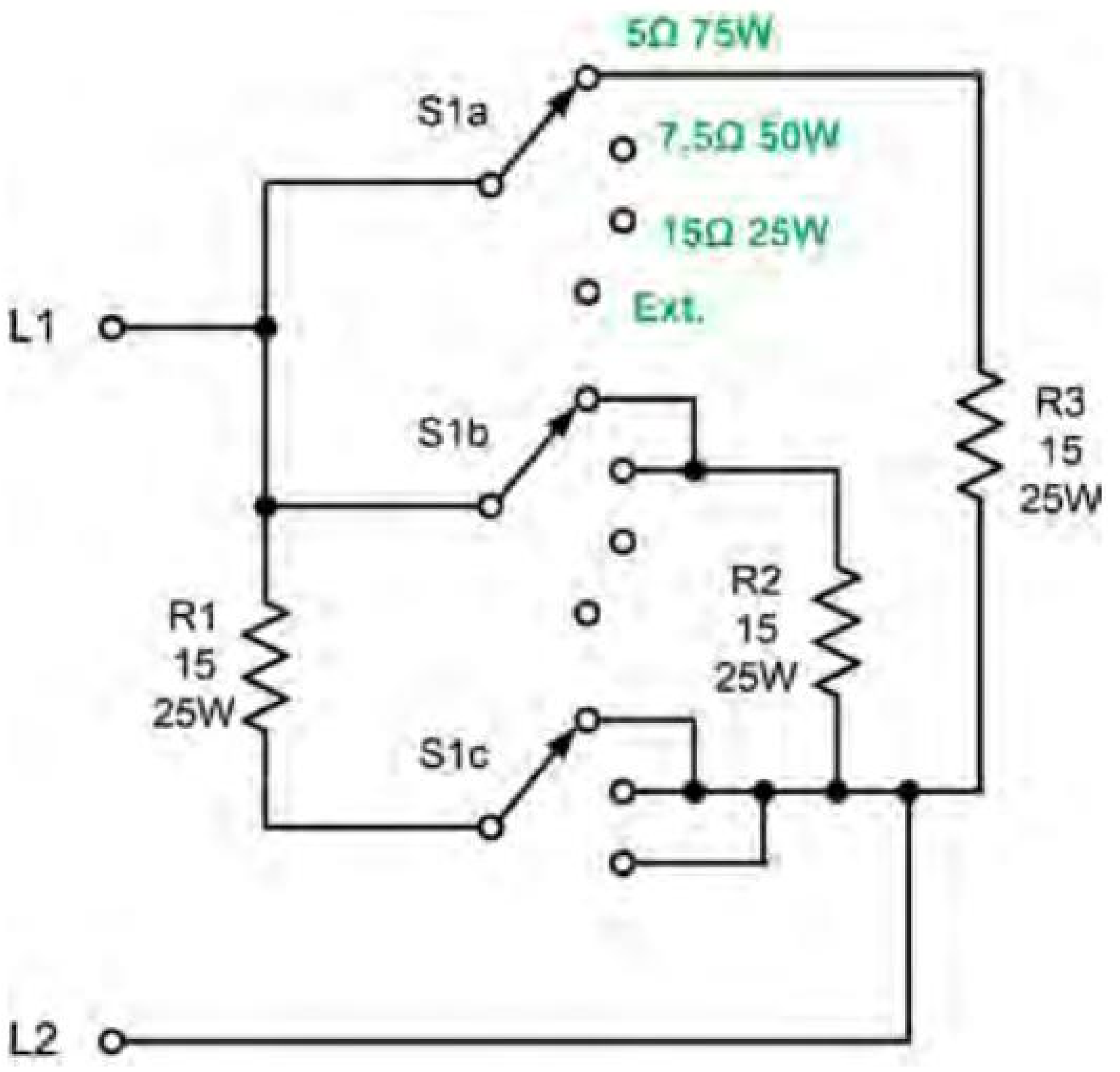


Fig.6.2. The load module

with audio power measurement and its specification. The term defines the output of an amplifier when delivered on a sustained basis and the Federal Trade Commission (FTC) standard, originally published in 1974, requires that, before measuring the output power, an amplifier should be 'preconditioned'. The FTC states that this process should involve operating the amplifier with all channels simultaneously driven at one third of rated output power for a period of one hour. The FTC standard also specifies the temperature (25°C) at which the measurement should be carried out and further states that it should be carried out at 'all frequencies within the power band' and 'without exceeding the rated maximum percentage of total harmonic distortion' (THD). Importantly, the FTC required that the rated power output should be sustainable for a period of not less than five minutes. Given the strictness of the FTC standard, it is somewhat disappointing that several manufacturers and suppliers are still making ridiculous and nonsensical claims for the equipment that they supply.

IEC (BS EN) 60268

The most recent international standard for specifying amplifier performance is defined in IEC (BS EN) 60268 Part 3 'Sound system equipment: Amplifiers'. Published in 2013, this standard applies not only to conventional analogue amplifiers, but also to the analogue parts of analogue/digital amplifiers that form part of a sound system for professional or household applications. The standard specifies the characteristics which should be included in specifications of amplifiers and the corresponding methods of measurement. In particular, it defines methods for measuring the short-term, long-term and temperature-limited output power of an amplifier.

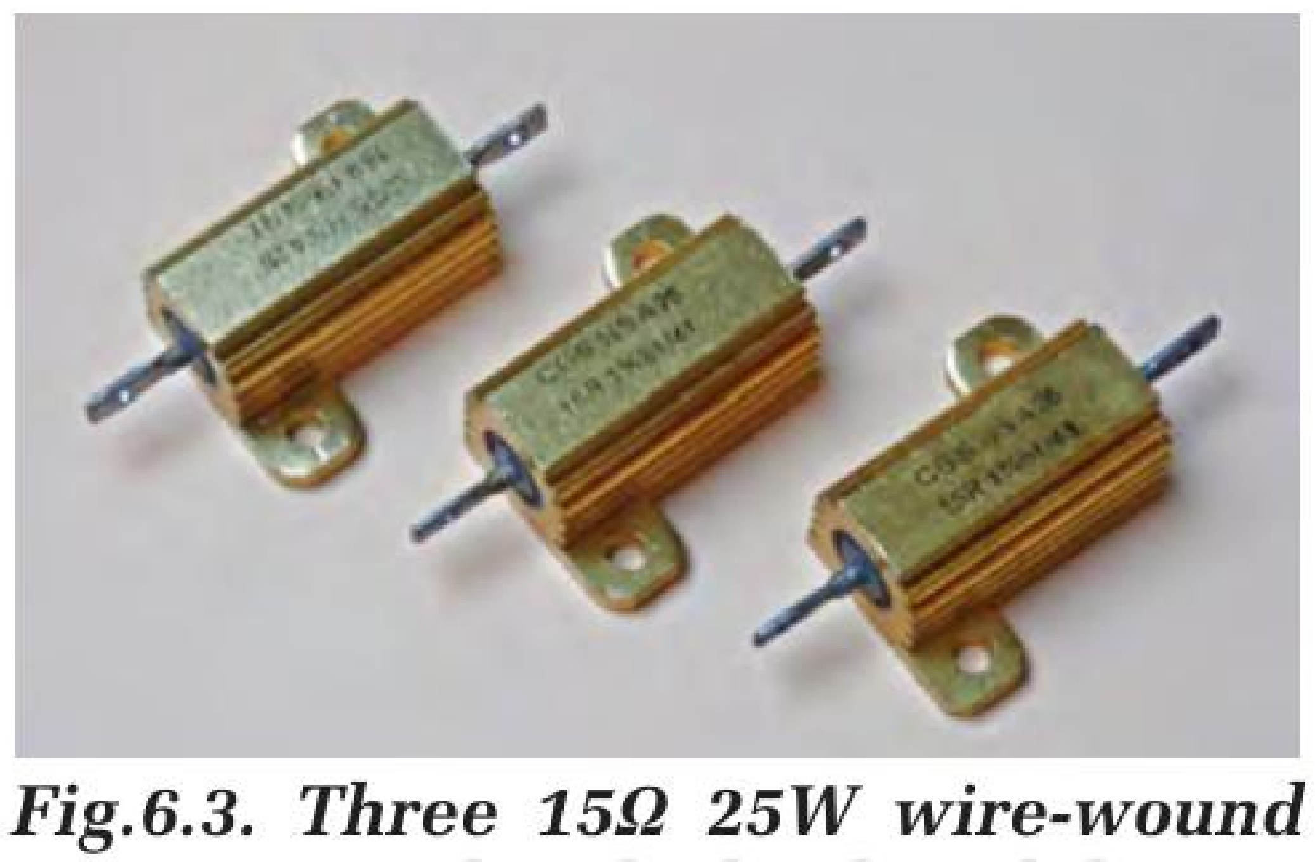


Fig.6.3. Three 15Ω 25W wire-wound resistors used in the load module

A simple power meter

Fortunately, a simple and effective power meter can be constructed from only a handful of commonly available components, and it can be a useful addition to the test instruments available in a workshop or laboratory, particularly when combined with a load, which can be used for testing without the need for a loudspeaker to be connected. For convenience, we built our power meter in two parts, an indicating module (based on a standard 1mA meter movement) and a resistive load module.

Indicating module

The circuit of the indicating module is shown in Fig.6.1 and the switched resistive load is shown in Fig.6.2. Four silicon diodes (D1 to D4) act as a bridge rectifier that produces DC for the moving coil meter, M1. In order to reduce the forward voltage drop associated with the diodes in the bridge arrangement, a small bias voltage is applied to the meter. This bias voltage is derived from three forward-conducting diodes, D5 to D7. A miniature pre-set potentiometer (RV1) provides a means of full-scale calibration, while a second miniature pre-set (RV2) provides bias adjustment (see later). Note that the connections to the load module R_L are made at points L1 and L2 (see Fig.6.1).

Load module

When testing a power amplifier it will usually be necessary to provide a suitably rated load rather than to make use of a loudspeaker (note that the impedance of a driver is often subject to quite a wide variation over the range of frequencies for which it is designed to be used and also varies according to the enclosure in which it is used). The test load should not only be purely resistive, but it should also be adequately rated in terms of power dissipation. For most practical purposes this means that one or more high-power resistors will be required, and using a suitable combination of series and/or parallel components it is possible to provide several different load resistances.

The circuit of our load module is shown in Fig.6.2. The load can be switched to provide load values of 5Ω, 7.5Ω and 15Ω at maximum power ratings of 75W, 50W and 25W respectively. To realise these values we used three high-power aluminium clad wire-wound 15Ω resistors. Each resistor was rated at 25W when mounted and used according to the manufacturer's recommendations (note that the manufacturer suggests de-rating by 50% when the resistors are not used with a heat dissipating surface or when they are used at a high ambient temperature). The resistors Arcol part number 'HS25 15RJ' (or similar) are available from several electronic component suppliers, including Rapid Electronics (stock code 62-8430).

Calibration

Calibration of the simple power meter can be carried using a load resistor, an RMS-reading AC voltmeter and an appropriately rated power amplifier fed with a sinusoidal signal at a frequency of 1kHz, see Fig.6.4. The dummy load must be adequately rated in terms of power and have a resistance that will match the nominal load resistance required by the amplifier (often this will be 4Ω, 8Ω or 15Ω, but the 5Ω, 7.5Ω or 15Ω resistances offered by our switched-load arrangement will usually prove satisfactory).

The amplifier should first be adjusted to provide the required full-scale value of power in the dummy load (indicated by the RMS voltage appearing across the load). Next, RV1 should be adjusted for full-scale deflection on the meter. The output power should then be progressively reduced and, at each step, the output power should

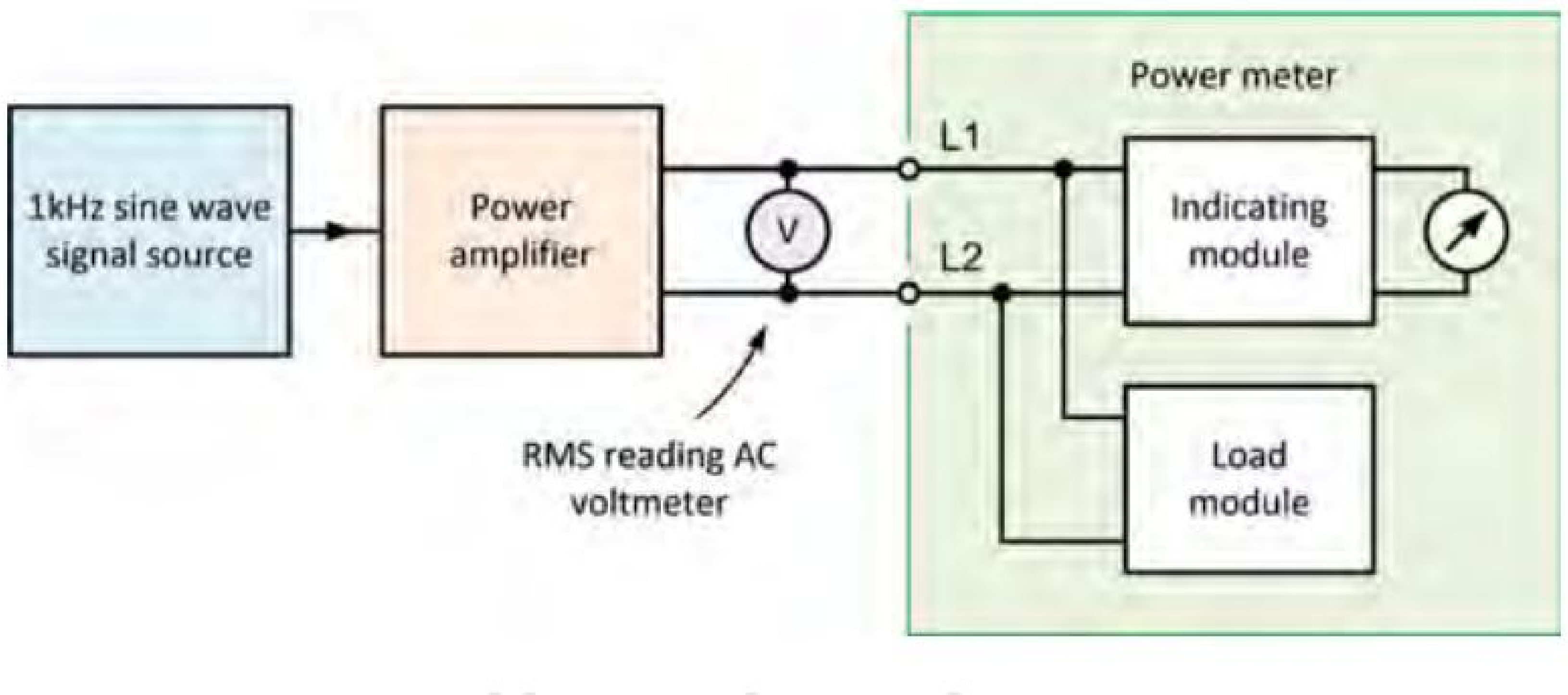


Fig.6.4. Calibrating the simple power meter

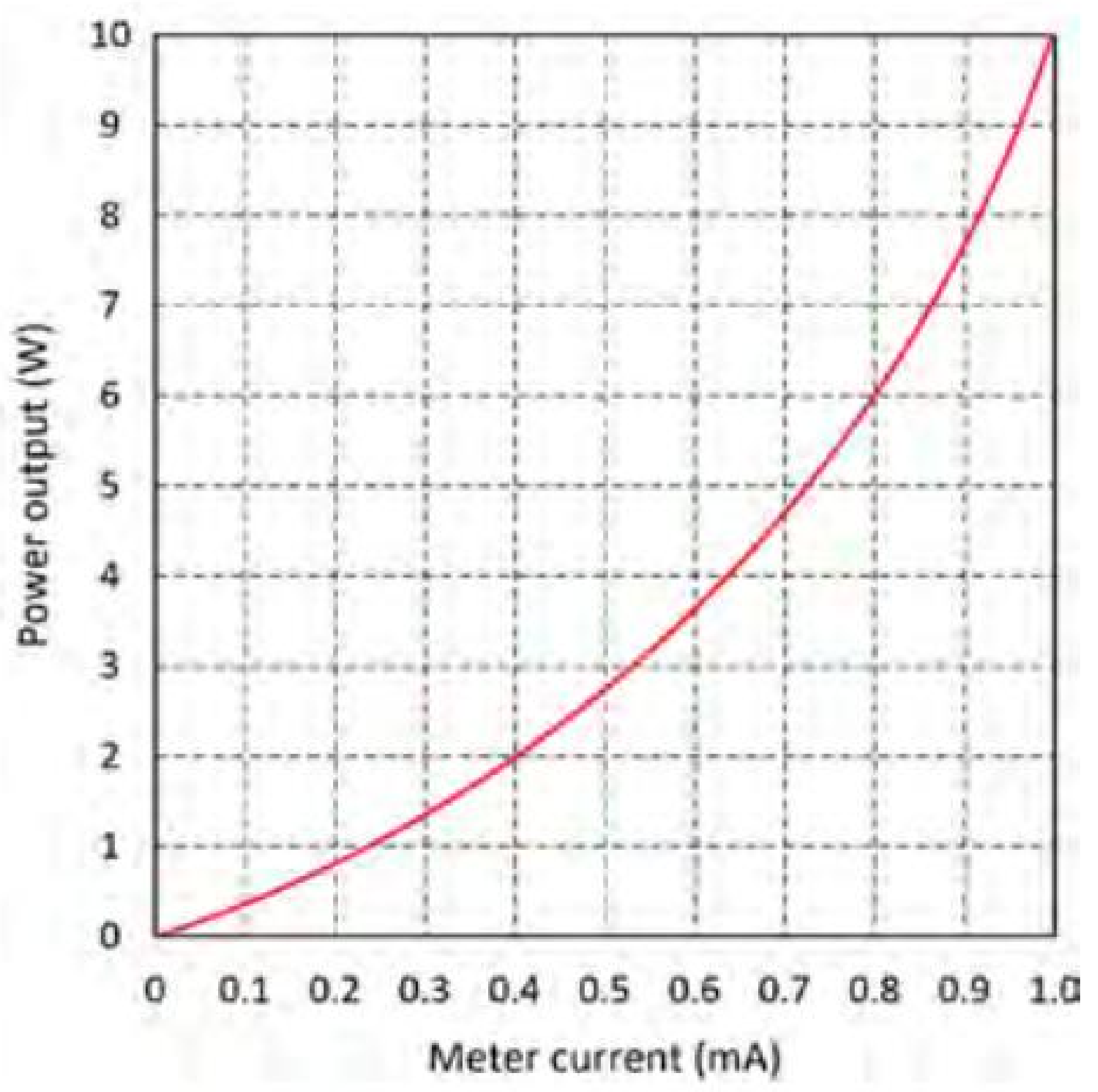


Fig.6.5. Calibration graph for the authors' prototype power meter when used with a 15Ω dummy load

be calculated (using the formula on page 36) and recorded along with the corresponding meter indication. This data can then be used to produce a calibration graph like the one shown in Fig.6.5. The procedure can be then be repeated for each value of load.

Knowledge Base: Some useful circuit building blocks

This month, we will be looking at some useful circuit building blocks in the form of the constant current and constant voltage sources found in a wide variety of analogue electronic applications, including the vast majority of power amplifiers. We will be meeting these circuits again in later instalments but, for the meantime, we will briefly explain each circuit and include some typical values. If you would like to experiment further with these circuits we've provided some Tina files that can be downloaded from the *EPE* website. These will enable you to test, modify and experiment with each of the circuit arrangements that we've described.

In an ideal world

Before we begin, it's worth explaining exactly what we mean by constant voltage and constant current sources and, in particular, how we would expect such a source to behave. The ideal constant voltage source shown in Fig.6.6(a) will maintain its rated output voltage regardless of the load that it is connected to (and consequently the amount of current that is drawn from it). The ideal constant current source shown in Fig.6.6(b) would be able to supply its rated current regardless of the load connected to it.

In the real world

In a real, imperfect, world we need to allow for the fact that things are rarely 'ideal' and, in particular, we need to allow for the fact that there is inevitably some resistance present in our circuits. In each case, there are two resistances present that we need to account for; the resistance present 'inside' our source as well as the resistance of the circuit load to which it is connected. In the case of the constant voltage source, the internal resistance is shown in series with the source and load. On the other hand, for the constant current source, the loss resistance appears in parallel with the source, as shown in Fig.6.7.

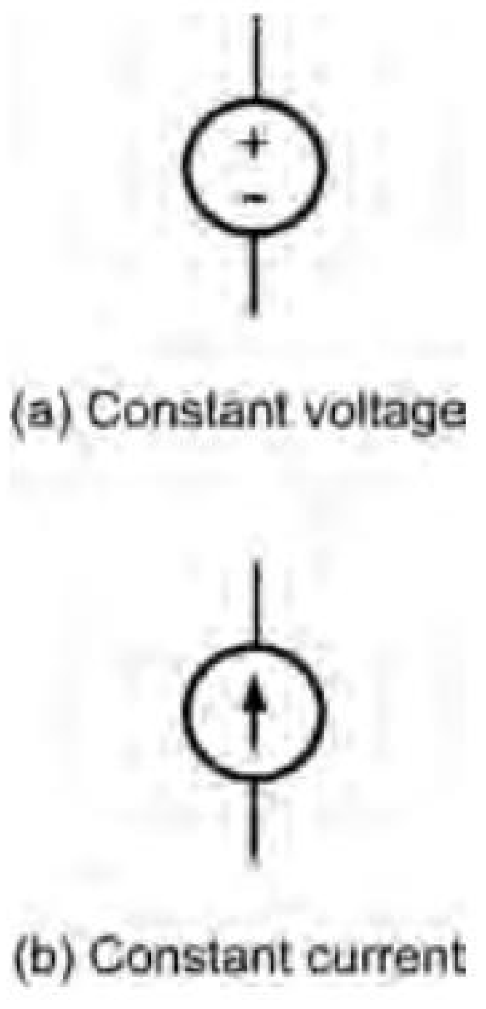


Fig.6.6. Symbols used to represent ideal constant voltage and constant current sources

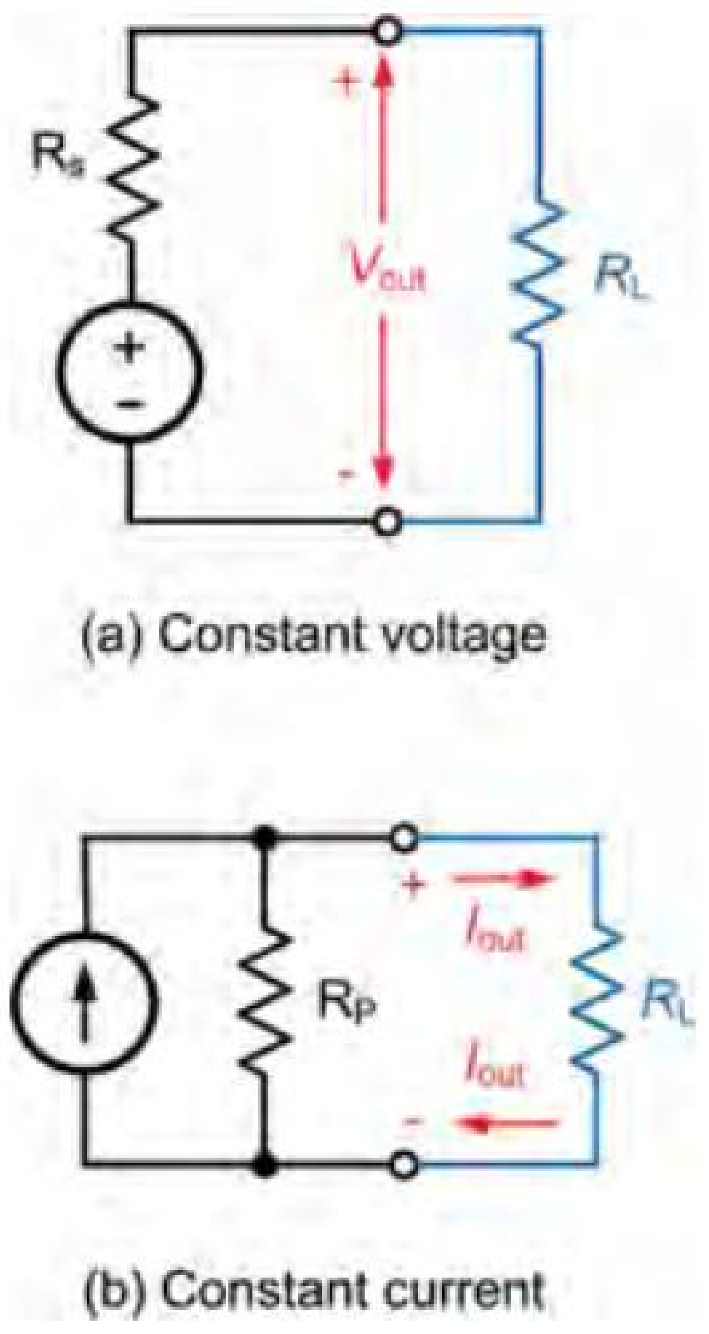


Fig.6.7. Effect of resistance on the constant voltage and constant current sources

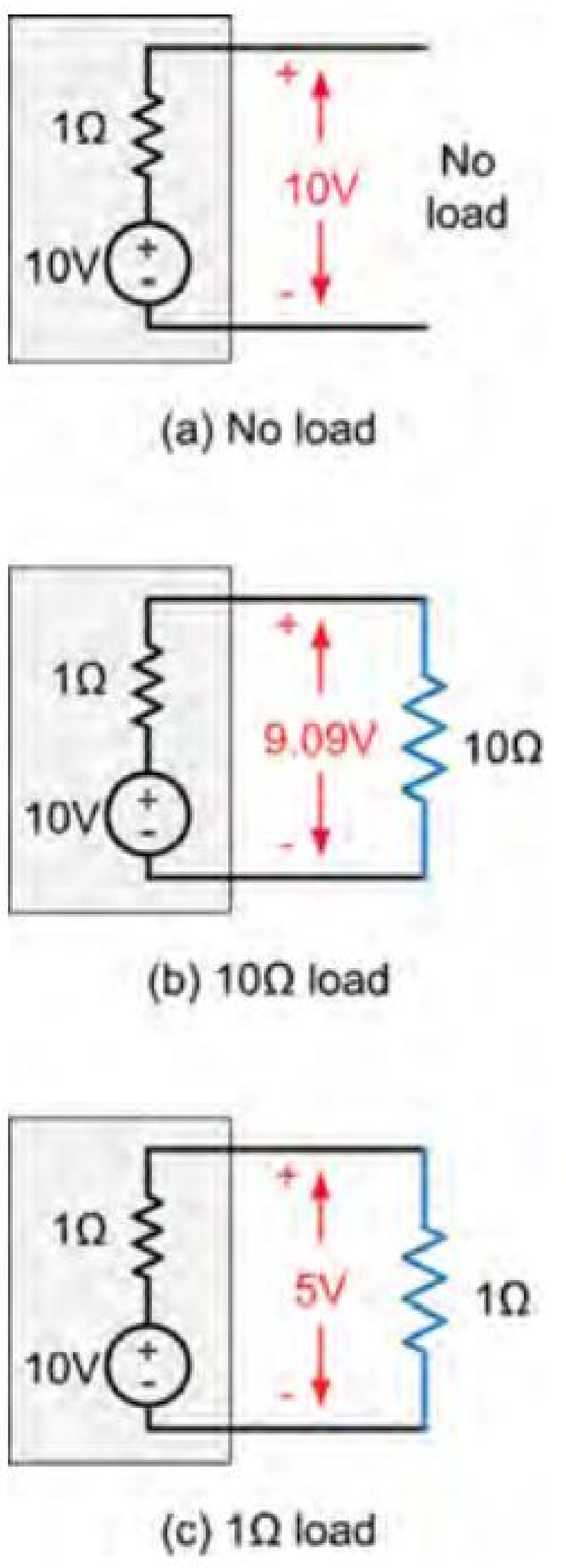


Fig.6.8. Example of a loaded voltage source

It's important to be aware of the effect of the two 'real world' resistances on the performance of the circuits shown in Fig.6.7. Taking the constant voltage arrangement as an example, let's assume that we have a voltage source of 10V which has an internal series resistance of 1Ω (see Fig.6.8). With no load connected (ie, a load having infinite resistance) the output voltage appearing across the terminals of the source would be 10V. With a load resistance of 10Ω the output voltage would fall to 9.09V and with a load resistance of only 1Ω (the same as that of the source itself) the output voltage would fall to a mere 5V. Under these conditions our source can hardly be described as 'constant voltage'!

It should now be clear that the resistances present in our constant voltage and constant current sources have a considerable impact on the way the circuits behave and, in particular, how close they conform to the ideal. To summarise:

- In the constant voltage source, series resistance R_S should be very small compared with the circuit load, R_L
- In the constant current source, parallel (shunt) resistance R_P should be very large compared with circuit load, R_L.

Now let's move on and look at some practical circuits that exhibit constant current and constant voltage characteristics.

Constant current sources

A simple constant current source based on a PNP transistor is shown in Fig.6.9, while its NPN counterpart is shown in Fig.6.10. These two circuits exploit the constant current characteristic of a transistor when operated in common-emitter mode (see *Teach-In 2015* part 2). In both circuits the base voltage is held constant by the two forward-biased silicon diodes and this produces a value of collector current that remains reasonably constant when the supply voltage (V_{IN}) and load resistance (R_L) is varied over a fairly wide range. The amount of current supplied (I_{out}) is determined by the value of emitter resistance (R_E) and can be calculated from:

$$I_{out} = \frac{0.7}{R_E}$$

With R_E set to 100Ω the output current will thus nominally be 7mA. In practice, it will vary from about 6.5mA with an input of 10V to 7.6mA with an input of 30V. Fig.6.11 shows this circuit modelled using Tina Design Suite. The output current produced by our two constant current sources can easily be made adjustable by simply replacing R_E with a pre-set resistor of appropriate value (220Ω or 470Ω being typical) as shown in Fig.6.12.

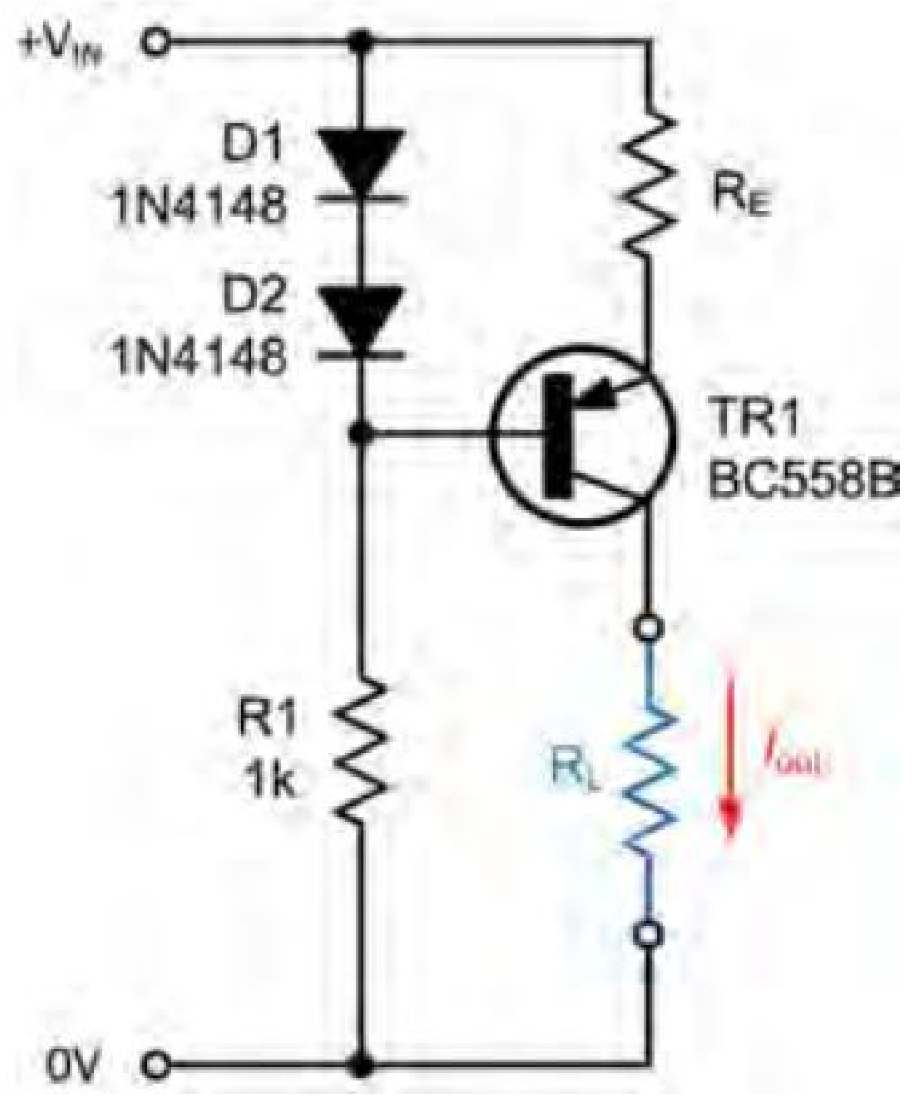


Fig.6.9. A simple constant current source based on a PNP transistor

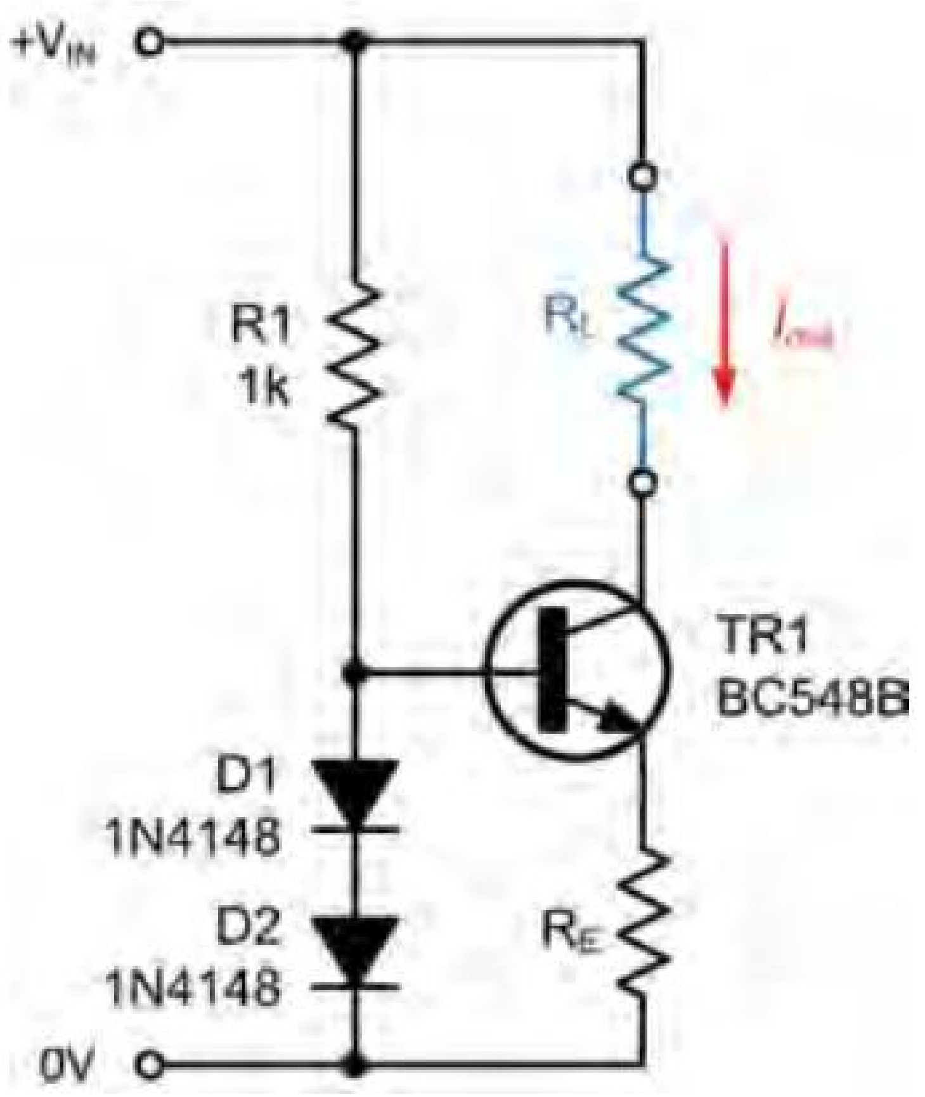


Fig.6.10. A simple constant current source based on an NPN transistor

Constant voltage sources

A simple constant voltage source can be based on nothing

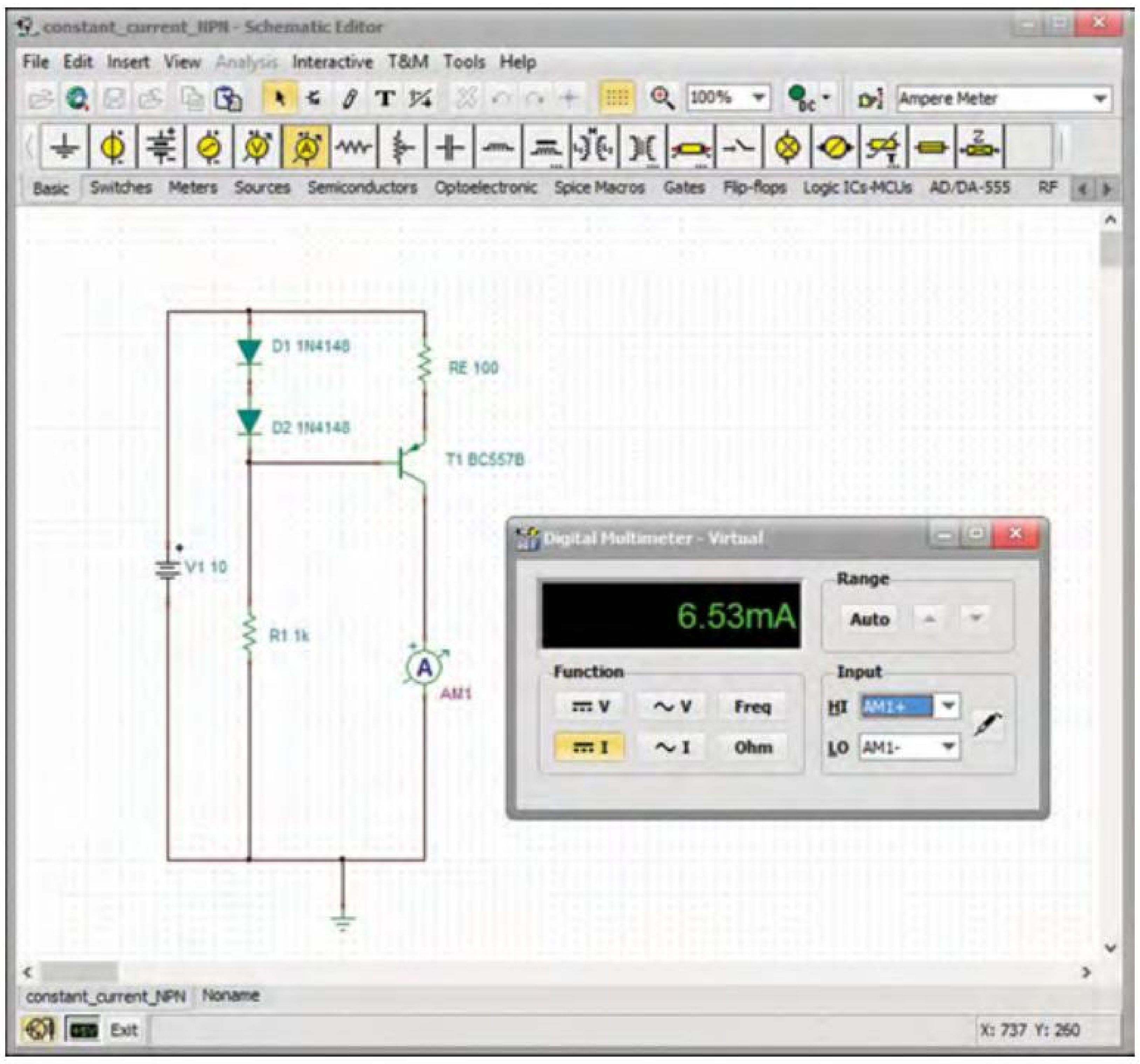
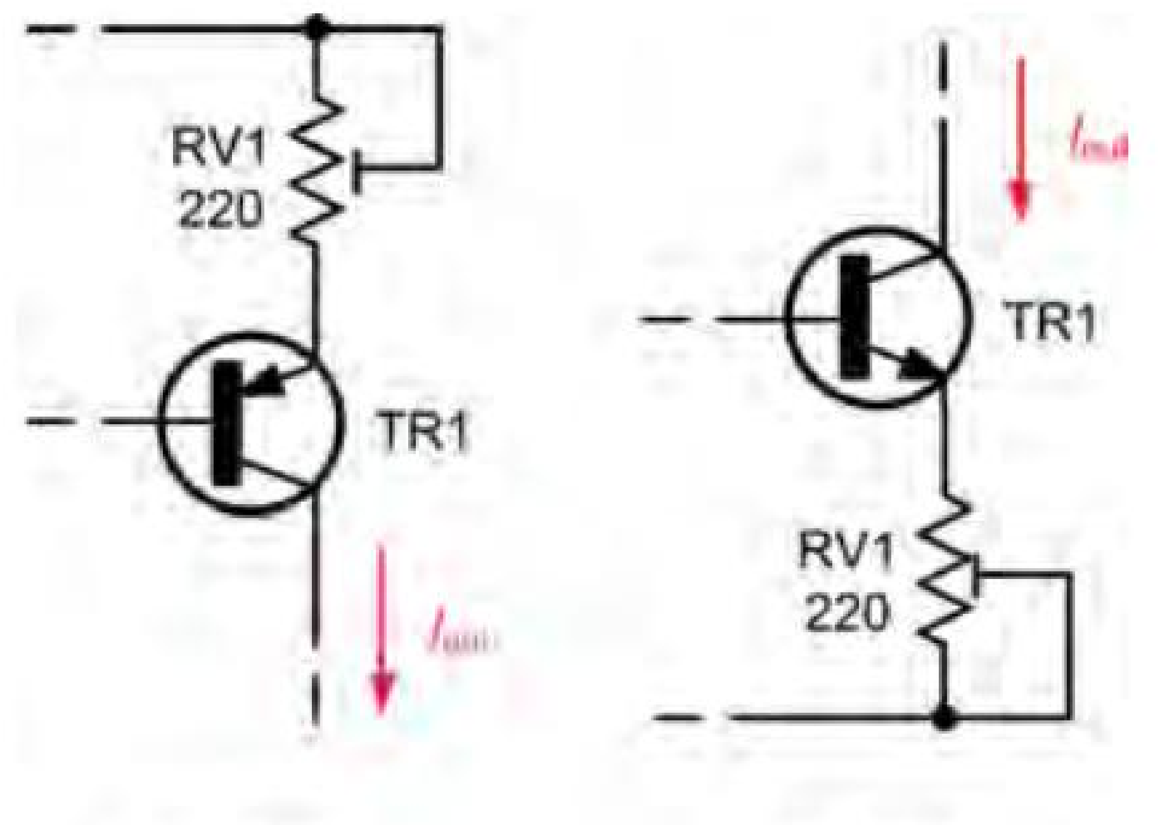

constant_current_NPN - Schematic Editor
File Edit Insert View Analysis Interactive T&M Tools Help
100%
Ampere Meter
Basic Switches Meters Sources Semiconductors Optoelectronic Spice Macros Gates Flip-flops Logic ICs-MCUs AD/DA-555 RF
D1 1N4148
D2 1N4148
RE 100
T1 BC557B
V1 10
R1 1k
AM1
Digital Multimeter - Virtual
6.53mA
Range
Auto
Function
Freq
Ohm
Input
HI AM1+
LO AM1-
constant_current_NPN Noname
Exit
X: 737 Y: 260

Fig.6.11. The circuit of Fig.6.9 modelled using Tina Design Suite (this, and the other circuits described this month, can be downloaded from the EPE *website)*


RV1
220
TR1
I_{out}
TR1
I_{out}
RV1
220

(a) PNP (b) NPN

Fig.6.12. Making the output of the constant current sources adjustable

more than a Zener diode acting as a shunt voltage regulator, as shown in Fig.6.13. This circuit clamps the supply at the Zener voltage (approximately 3V in the case of Fig.6.13) and with the values shown the circuit produces a no-load output voltage of 3V when supplied from 5V rising to about 3.3V when the circuit is fed from 30V. Unfortunately, an important limitation of the circuit is its inability to deliver much in the way of load current and so, although this circuit can act as a useful voltage reference, it is generally unsuitable for use as a general purpose constant voltage source.

An improved arrangement using an added emitter-follower stage is shown in Fig.6.14. The output voltage is 0.7V less than the nominal Zener voltage (resulting in an output voltage of about 2.3V in the case of Fig.6.14). The circuit exhibits an effective internal resistance (R_S) of about 5Ω and with 10V input the circuit will supply load currents of up to about 20mA.

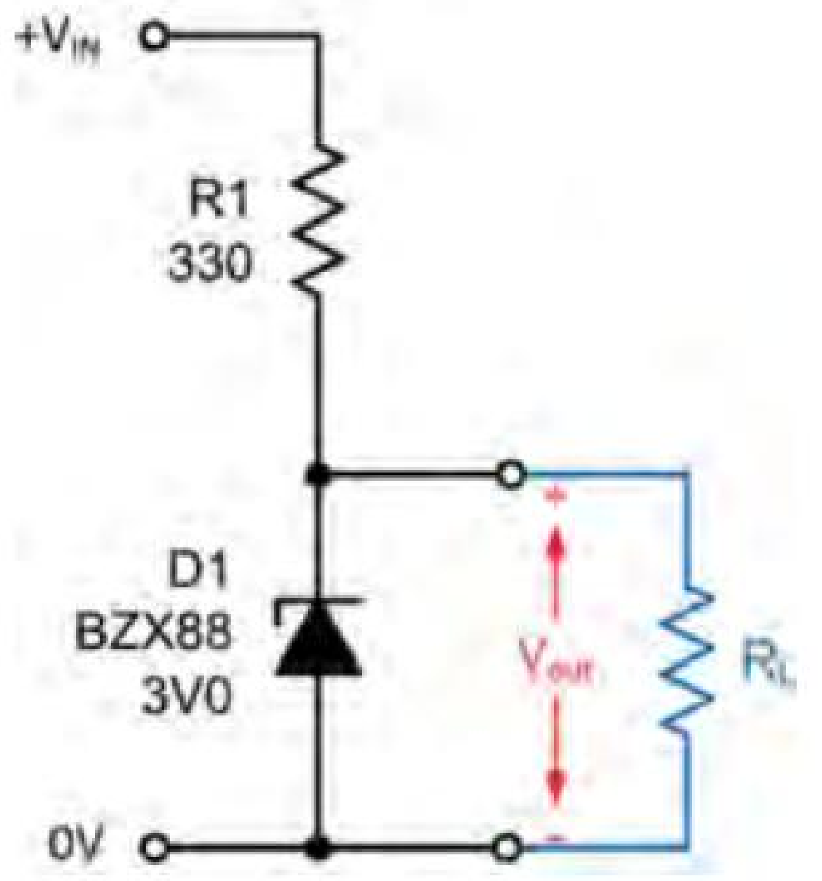

+V$_{IN}$
R1
330
D1
BZX88
3V0
V$_{out}$
R$_L$
0V

Fig.6.13. A simple voltage reference based on a Zener diode

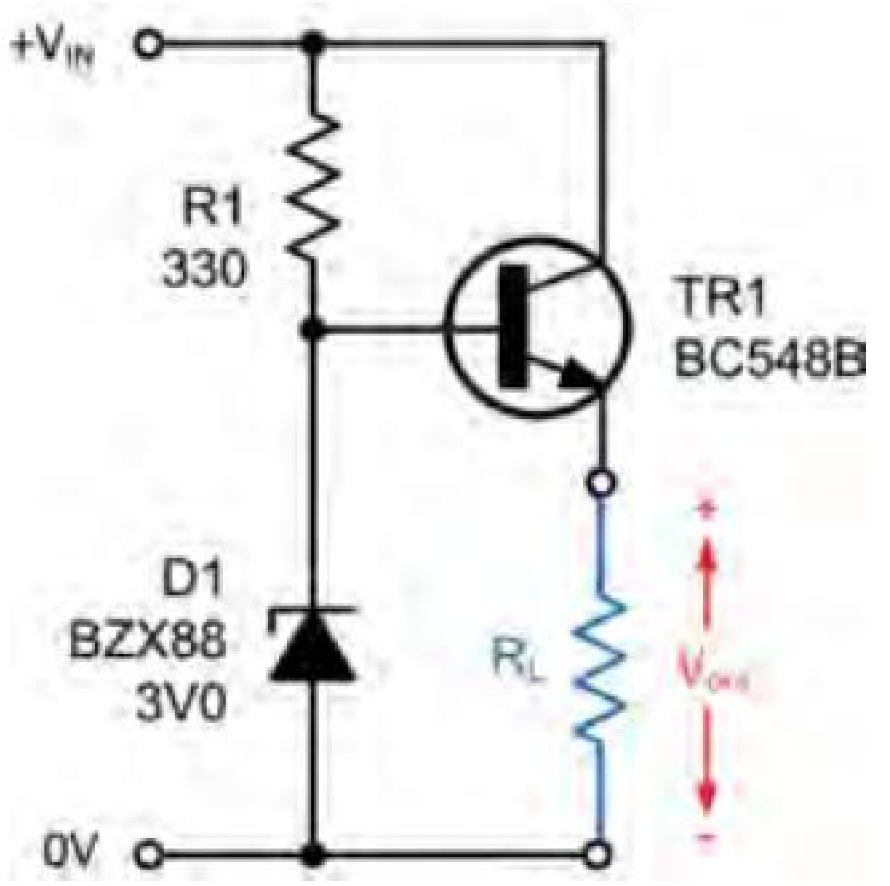

+V$_{IN}$
R1
330
TR1
BC548B
D1
BZX88
3V0
R$_L$
V$_{out}$
0V

Fig.6.14. Using an emitter follower to increase the output current produced by the simple voltage regulator

The output voltage of the circuit shown in Fig.6.14 can be adjusted by adding a pre-set variable resistor, as shown in Fig.6.15. With the values shown, and using a nominal 10V supply, the output voltage can be adjusted from approximately 3V to 6V.

A further circuit refinement involves using a constant current source to feed the Zener reference as shown in Fig.6.16. This circuit provides a very stable constant voltage source. With the values shown in Fig.6.16, the no-load output voltage varies from 3.01V with 5V input to 3.04V with 30V input. It's worth comparing this performance with that of the simple shunt Zener circuit described earlier in Fig.6.13.

Get Real: Testing the simple tone control

Our third *Get Real* project (described last month) was a tone control that can be used in conjunction with our two previous projects, as well as those that follow. The module provides separate treble and bass controls and is based on a Baxandall circuit arrangement.

Table 6.1 Transistor bias voltages under simulated and real conditions

Device	Terminal	Simulated voltage (Tina)	Real voltage (lab. measurement)
Q1 (T1)	Emitter	0.02V	0.04V
	Base	0.64V	0.68V
	Collector	2.06V	3.23V
Q2 (T2)	Emitter	1.40V	2.56V
	Base	2.06V	3.23V
	Collector	9.00V	9.25V

First we used Tina Design Suite to check the DC bias conditions, ensuring that both transistors were operating in linear (Class A) mode. Table 6.1 shows the voltages our measurements yielded (for comparison we've included the measurements made on our prototype circuits using real components). Further investigation showed that the large difference in voltages for TR2 was attributable to the wide variation in h_{FE} (200 to 450) for the 'B gain group' of BC548 devices. This underlines the need to use negative feedback in order to ensure that active devices remain correctly biased when different transistors are used.

During the design phase we used Tina Design Suite to select component values that will produce a reasonable amount of boost and cut in both the treble and bass frequency ranges (50Hz to 200Hz and 5kHz to 10kHz, respectively). We

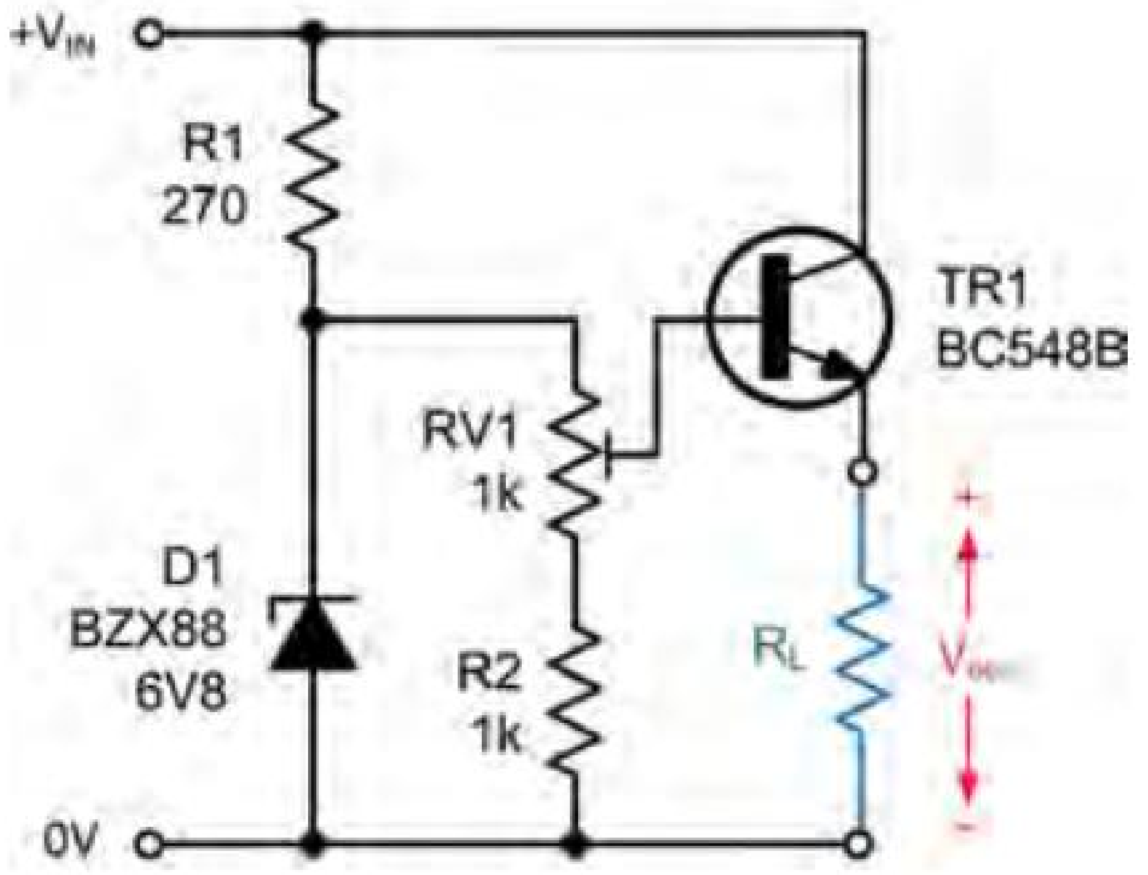

+V$_{IN}$
R1
270
TR1
BC548B
RV1
1k
D1
BZX88
6V8
R2
1k
R$_L$
V$_{out}$
0V

Fig.6.15. Making the output of the constant voltage source adjustable

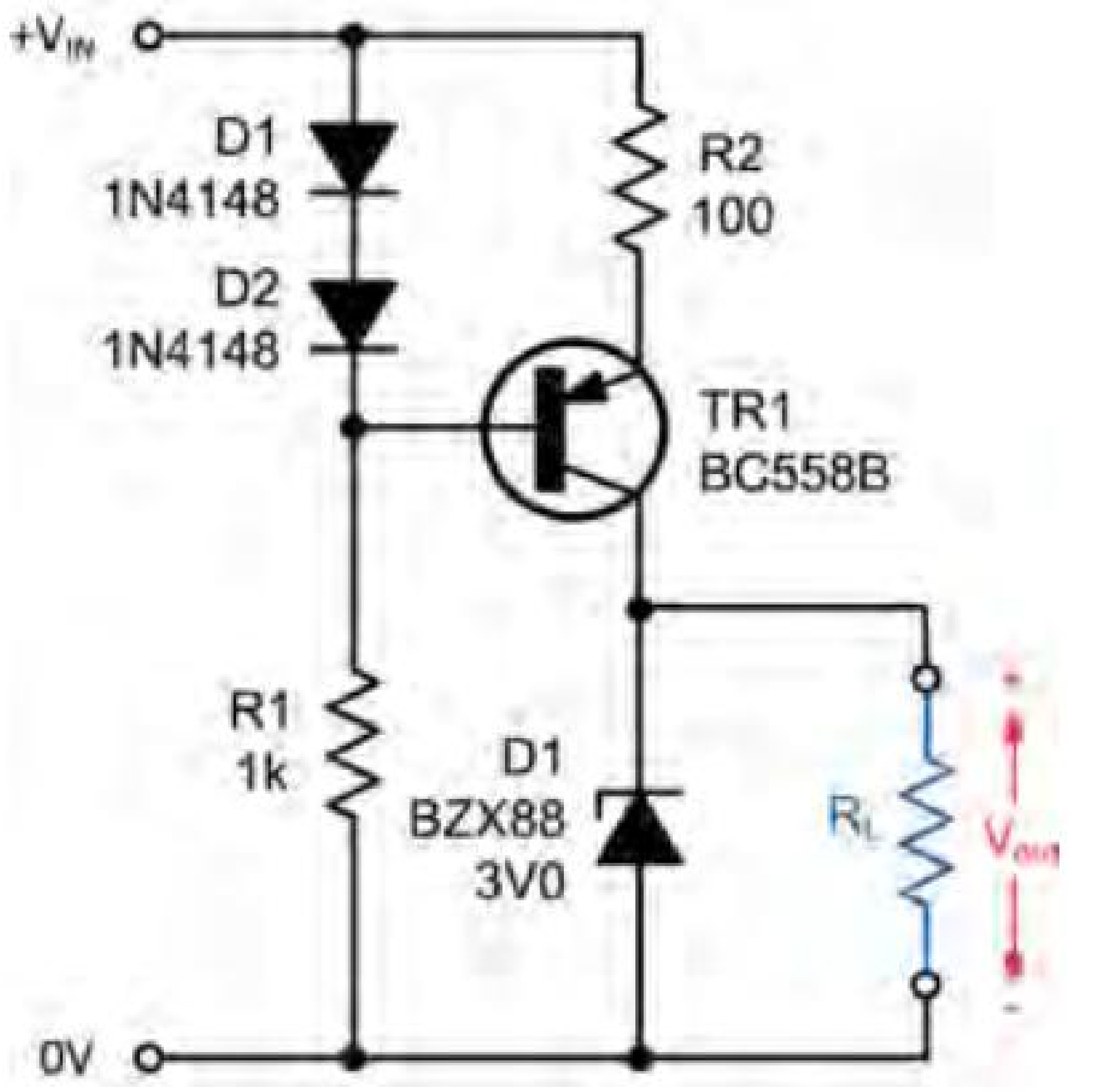

+V$_{IN}$
D1
1N4148
R2
100
D2
1N4148
TR1
BC558B
R1
1k
D1
BZX88
3V0
R$_L$
V$_{out}$
0V

Fig.6.16. Improved voltage reference using a constant current source to feed the Zener

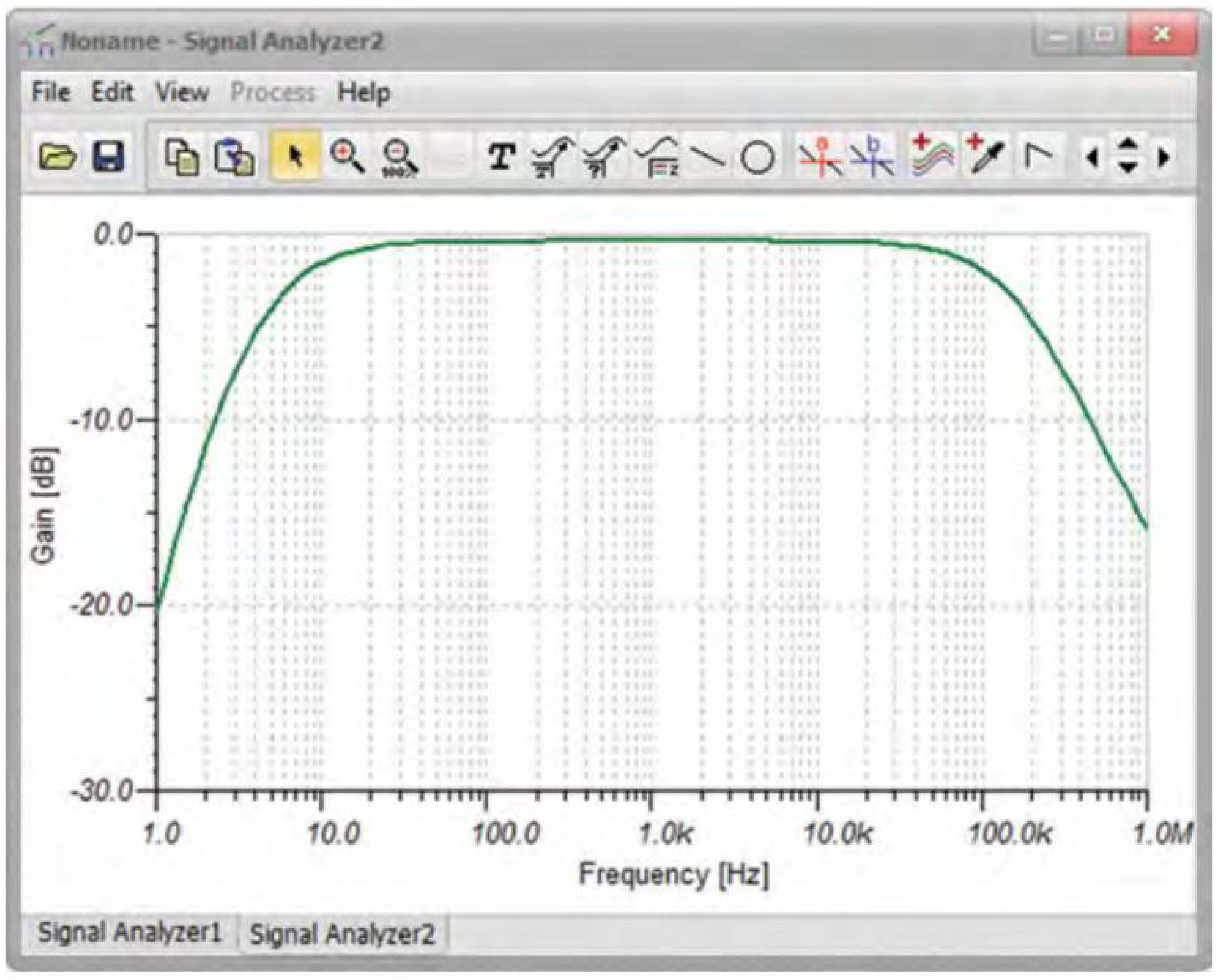


Fig.6.17. Frequency response of the simulated circuit (both controls placed in the mid-position)

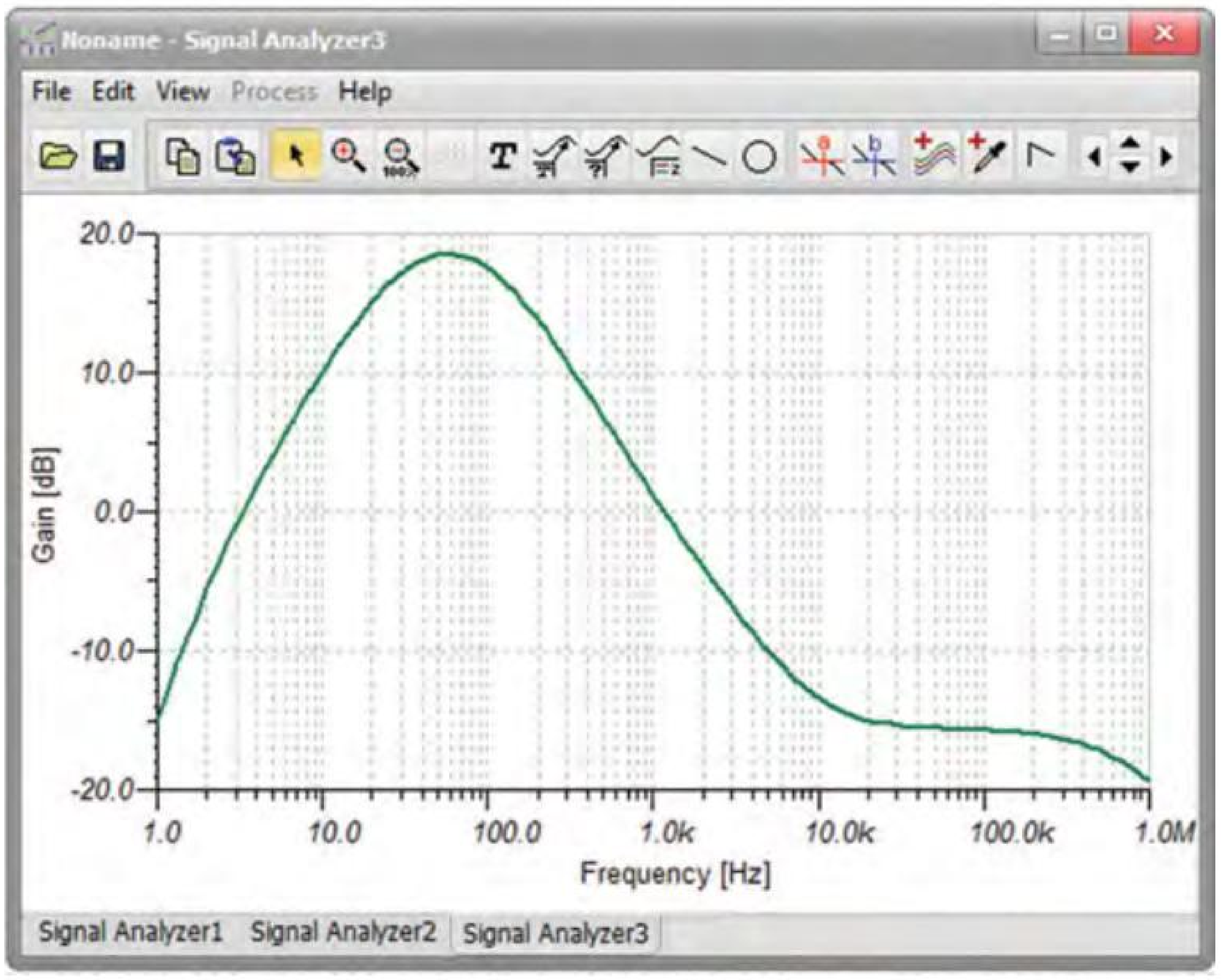


Fig.6.18. Frequency response of the simulated circuit with controls set for maximum bass and minimum treble

Table 6.2 Comparison of measured and simulated circuit performance

Specification	Design objective	Simulated (TINA)	Measured
Mid-band voltage gain (see Note 1)	1	1	1
Frequency response (set to 'flat')	Better than 10Hz to 100kHz at –3dB	7Hz to 180kHz at –3dB	6Hz to 150kHz at –3dB
Treble control range	Greater than ±12dB at 10kHz	17dB 'boost'; 14dB 'cut'	15dB 'boost'; 14dB 'cut'
Bass control range	Greater than ±12dB at 100Hz	17dB 'boost'; 15dB 'cut'	14dB 'boost'; 18dB 'cut'
THD (see Note 2)	Less than 0.1%	Not measured	0.15%
Max. output	1V RMS at 0.5% THD	Not measured	0.5V RMS at 0.2% THD
Supply voltage	9V at less than 5mA	9V at 1mA	9V at less than 3mA

Notes

1. Measured at 1kHz with treble and bass controls both controls set to 'flat' (mid-position), 600Ω source and 10kΩ load resistance.
2. Measured at 100mV RMS output into a 10kΩ load resistance.

also wanted to ensure that, when the controls are set to the mid-position (corresponding to zero-cut and zero-boost) the circuit exhibits a truly 'flat' frequency response.

The frequency response of the simulated circuit was measured using Tina Design Suite with the two tone controls set to mid-position. The resulting response is shown in Fig.6.17 in which the lower and upper cut-off frequencies (6Hz and 200kHz respectively) are indicative of an excellent 'flat' response.

Having verified the 'flatness' of our tone control circuit without any 'boost' or 'cut' applied, we next used Tina Design Suite to measure the range of adjustment offered by the bass and treble controls. The results are shown in Fig.6.18 (maximum bass and minimum treble) and Fig.6.19 (minimum bass and maximum treble). Note from Fig.6.18 that the maximum bass boost is about 17dB (at around 60Hz) while the corresponding

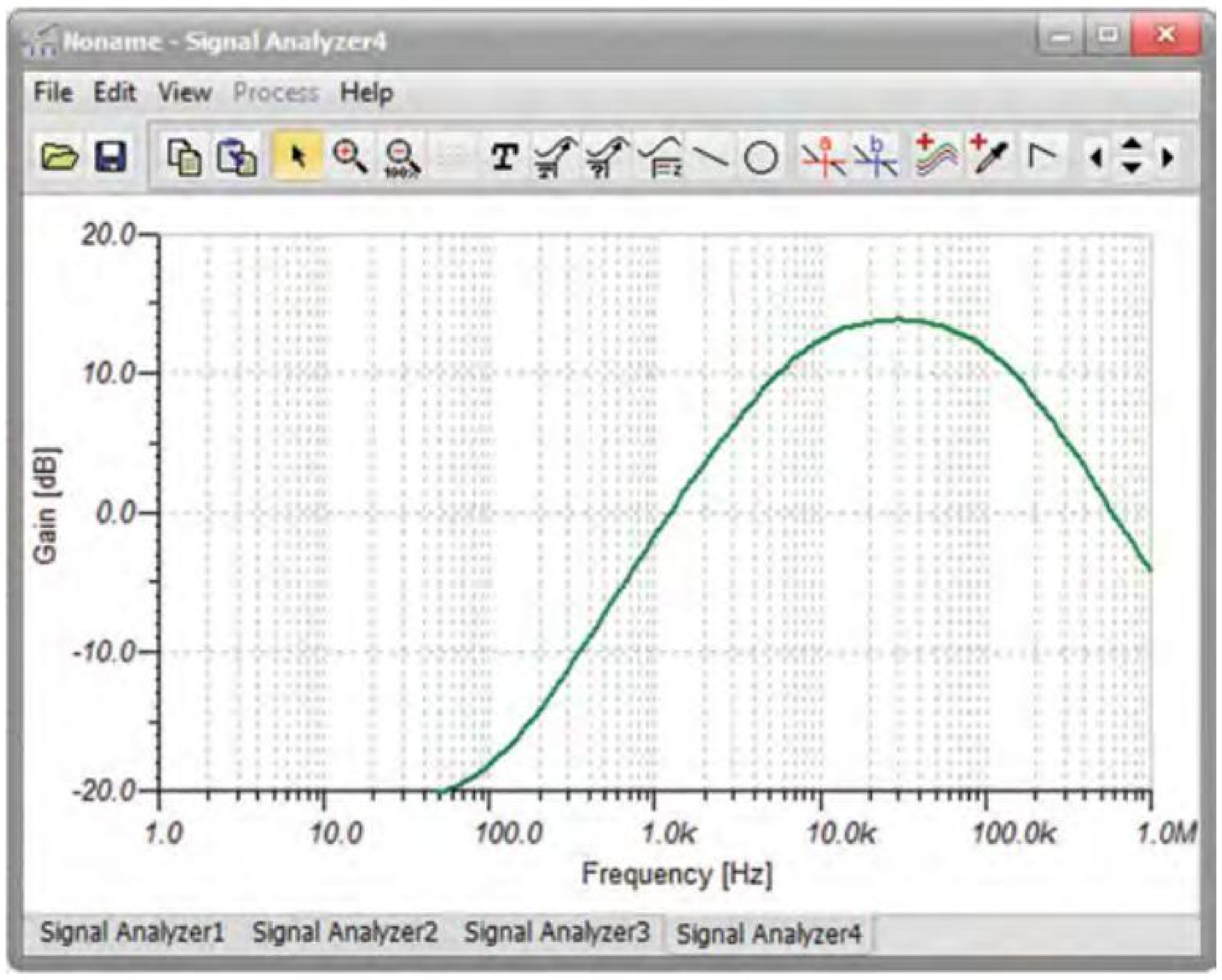


Fig.6.19. Frequency response of the simulated circuit with controls set for maximum treble and minimum bass

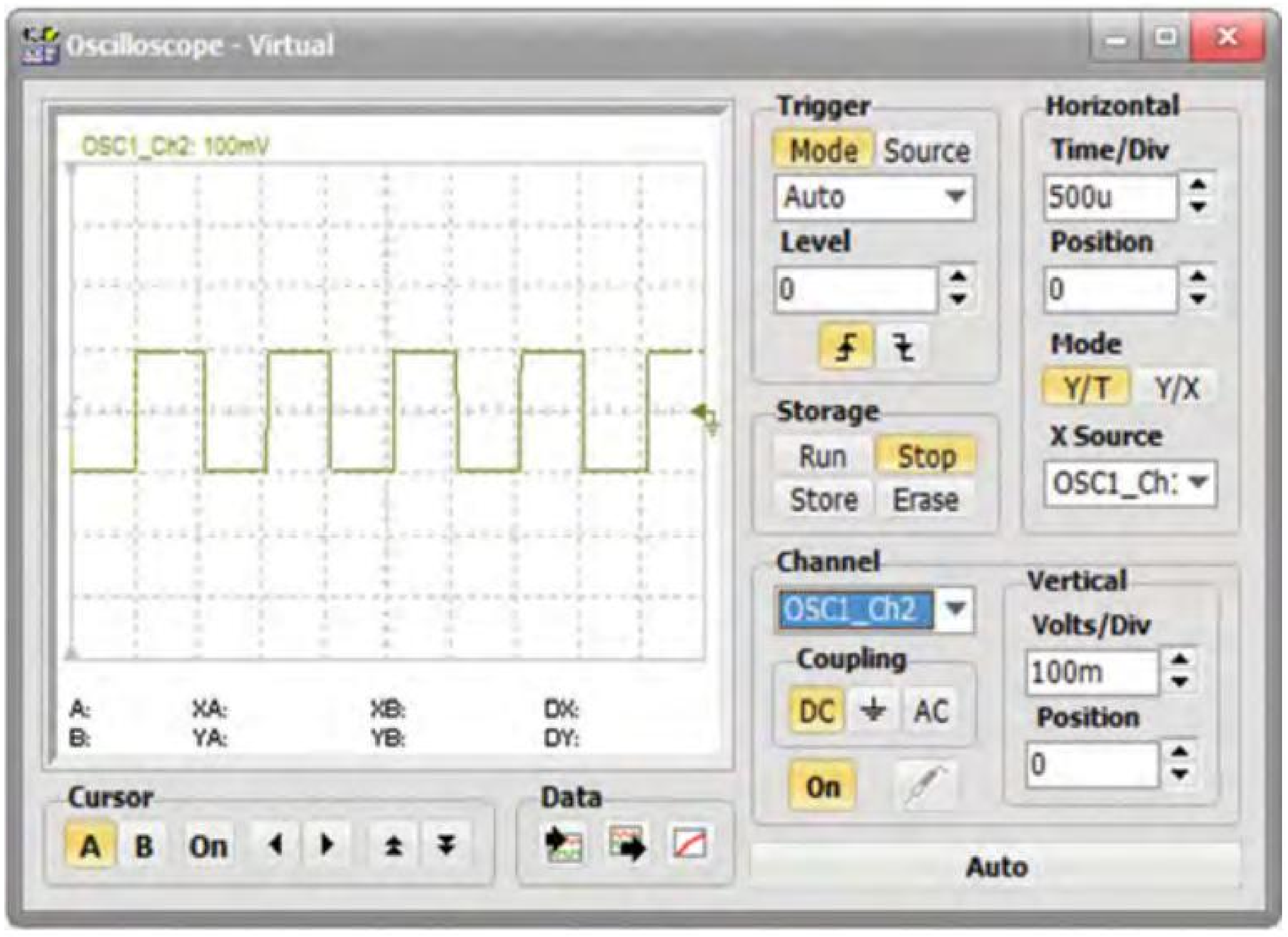

Oscilloscope - Virtual
OSC1_Ch2: 100mV
A:
B:
XA:
YA:
XB:
YB:
DX:
DY:
Trigger
Mode
Source
Auto
Level
0
Storage
Run
Stop
Store
Erase
Channel
OSC1_Ch2
Coupling
DC
AC
On
Horizontal
Time/Div
500u
Position
0
Mode
Y/T
Y/X
X Source
OSC1_Ch:
Vertical
Volts/Div
100m
Position
0
Cursor
A
B
On
Data
Auto

Fig.6.20. Square wave testing of the simulated tone control circuit (both controls placed in the mid-position). The screen was captured from Tina Design Suite

value of treble cut is about 14dB. From Fig.6.19, note that the maximum treble boost is a little more than 14dB (at around 20kHz) while the bass cut is more than 20dB.

Square wave testing

Earlier, in Part 4 of *Teach-In 2015* (see April 2015 *EPE*) we showed how some basic square wave tests can be used to provide a quick overview of the frequency response of an amplifier or filter. Let's put this into practice by testing our simulated and real tone control circuits using a square wave rather than a sinewave signal.

Fig.6.20 shows the simulated square-wave response at a test frequency of 1kHz when the treble and bass controls are both zeroed. Note that the output waveform appears to be perfectly square with no sag or droop evident. You might like to compare this waveform with the measured lab performance when a square wave was applied to the prototype circuit (see Fig.6.21).

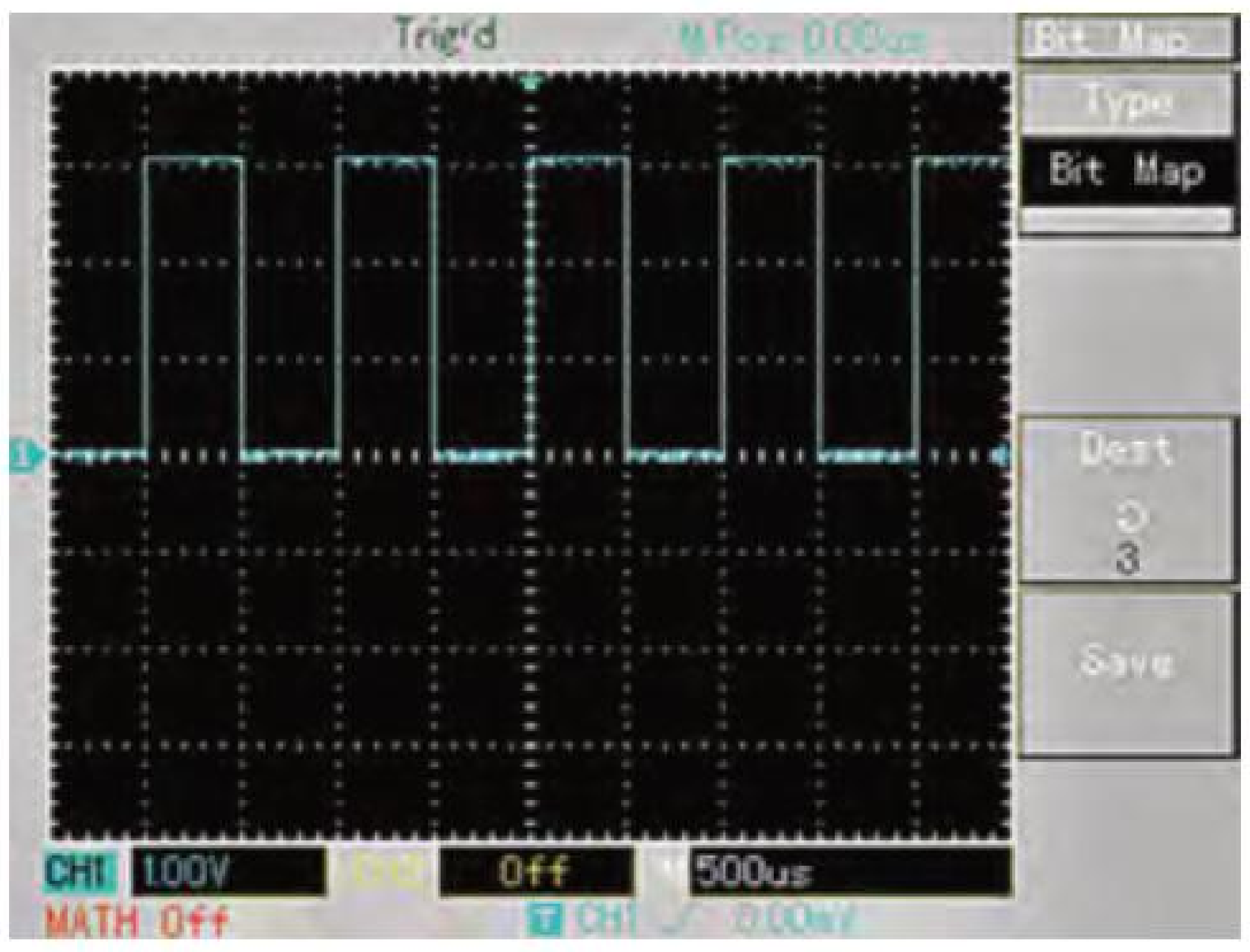


Fig.6.21. *Square wave testing of the real prototype circuit (both controls placed in the mid-position). This waveform was captured using a low-cost digital storage oscilloscope (DSO)*

Square wave tests at 1kHz were also carried out at the maximum 'boost' and 'cut' positions of the two tone controls. Results for treble 'boost' and 'cut' are shown in Fig.6.22 and Fig.6.23 respectively.

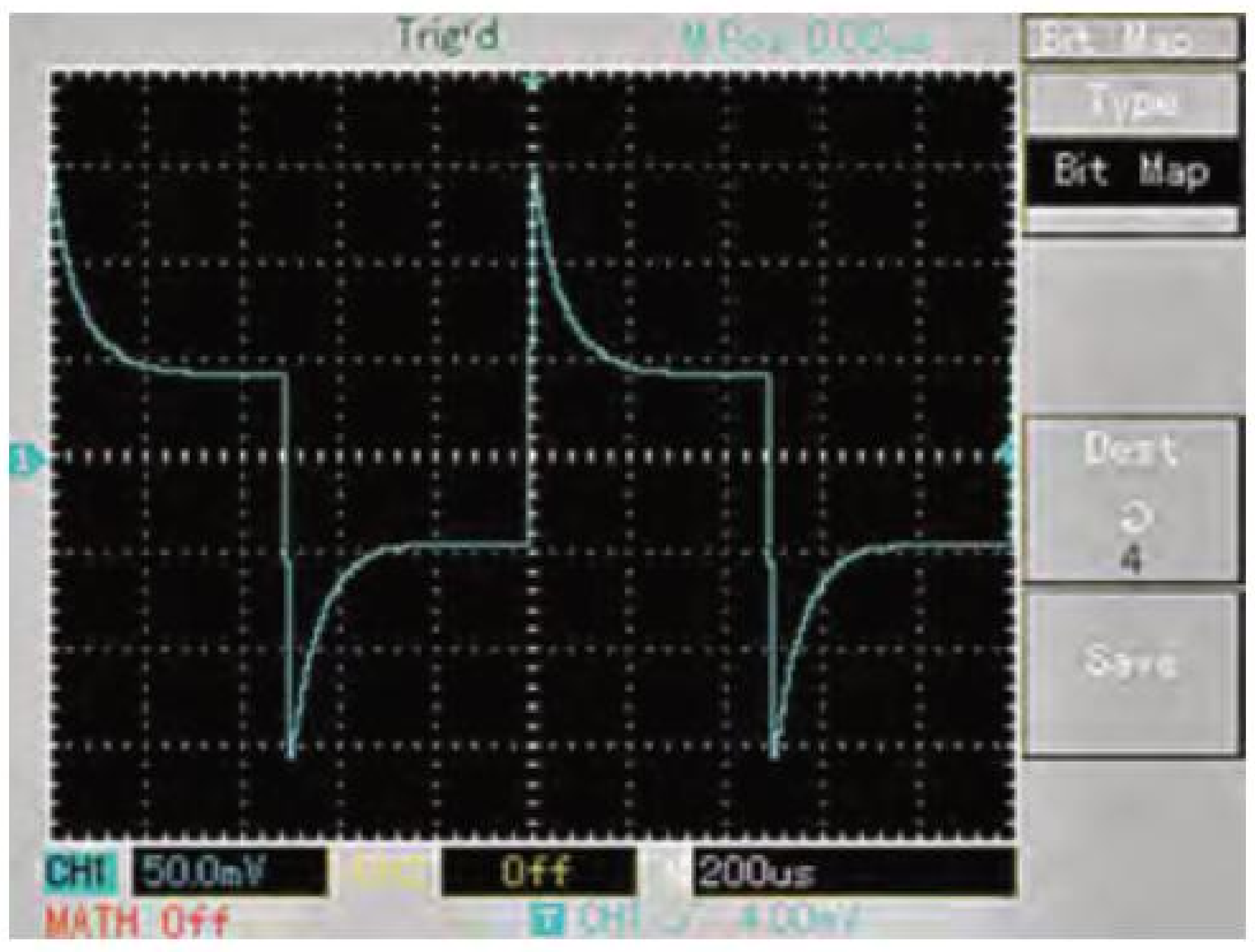


Fig.6.22. Square wave output corresponding to maximum treble 'boost'

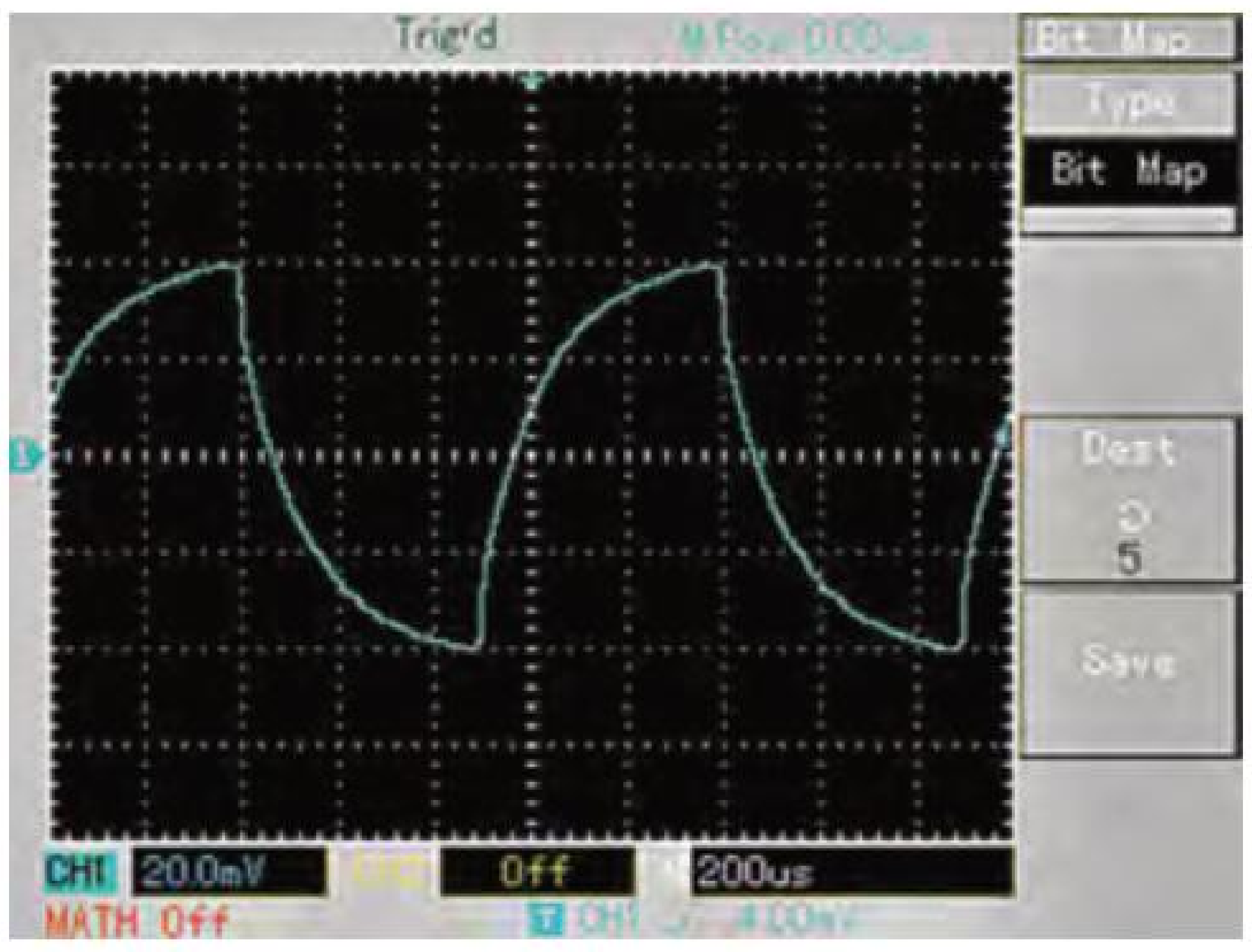


Fig.6.23. Square wave output corresponding to maximum treble 'cut'

The results of our simulation and measurements are shown, together with the original design objectives, in Table 6.2. Our measured results were within about ±3dB of the simulated performance and both bass and treble cut and boost exceeded our original requirement of greater than ±12dB.

Finally, when used with the simple headphone amplifier described earlier in the series, our listening tests confirmed the usefulness of the tone control circuit with several different loudspeakers and with a variety of different music styles.

Next month

In next month's *Teach-In 2015*, *Get Real* will describe the construction and use of a simple VU-meter. *Discover* will be devoted to heat sinks and heat sink design, while *Knowledge Base* will introduce you to some more circuit building blocks including the differential amplifier, the current mirror and the V_{BE} multiplier.

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Robert Penfold looks at the Techniques of Actually Doing it!

Ins and outs of diodes

THE vast number of different types of semiconductors can be bewildering for beginners. The semiconductor section of an electronic components catalogue is usually pretty huge, and in some cases there are literally thousands of different devices on offer. The diode is the most simple of the semiconductor components, and I suppose that it should be relatively easy for newcomers to deal with. However, even the humble diode exists in numerous incarnations.

Go with the flow

A diode acts as an electronic valve that allows a current to flow in one direction, but blocks any current flow if the polarity of the signal is reversed. It is obviously necessary to connect diodes the right way round if a circuit is to work properly. The two terminals of a diode are called the anode (a) and cathode (k). The circuit symbol for a diode is shown on the extreme left in Fig.1, and the arrowhead part of the symbol indicates the direction in which the current can flow. We are talking here in terms of conventional current flow from positive to negative, and the current flow is therefore from the anode to the cathode. The circuit symbol sometimes includes 'plus' and 'minus' signs to indicate the direction of flow for conventional current.

Fig.1 shows the way in which the polarity is indicated on a variety of actual diodes, and these methods are loosely based on the circuit symbol. The most common method is to have a band marked around the cathode end of the body, and this corresponds to the bar at the cathode end of the circuit symbol. These days, many diodes are marked with several bands, and these denote the type number using a system based on the resistor colour code. This leaves room for confusion, but the band near the cathode should be much more prominent than any of the others.

Diode or rectifier

Some diodes are more commonly referred to as rectifiers. These two types of component are essentially the same, but when referred to as 'diodes' the expectation is normally that the component in question can handle low-level signals and in many applications passes only minute currents. However, if a diode is called a 'rectifier', then it will be used in applications that handle relatively large currents, and this usually means some sort of power supply circuit. As a general rule, if a component is designed to handle currents of one amp or more it is a rectifier, but it is classed as a diode if it has a maximum current rating of much less than this.

Given that they are designed to handle high currents, the lead-out wires of the larger rectifiers can seem excessively thick. The lead-out wires of many large rectifiers are deliberately made very stout so that they conduct heat away from the component. In other words, the lead-out wires act as small heatsinks, and they are normally left relatively long so that they provide adequate cooling. This can make them difficult to solder to a circuit board, and often require a switch to a larger, more powerful soldering iron.

Diode shortcomings

On the face of it there should be no difficulty in producing what might be termed 'a diode for all occasions' or a universal diode that can be used in any circuit that needs an electronic valve. In the real world things are never as simple as that, and this is simply because even the best of modern semiconductor diodes fall

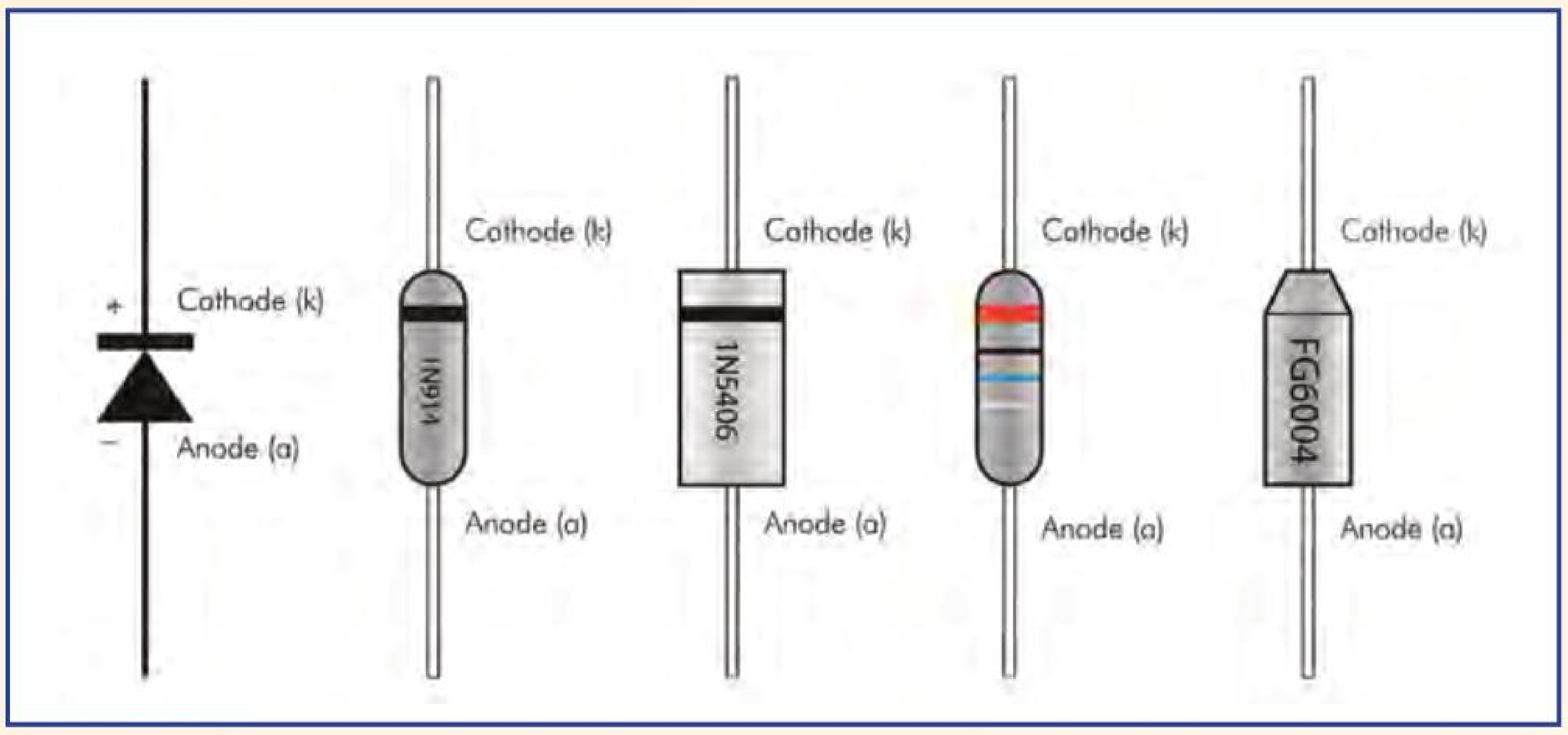


Fig.1. The diode circuit symbol is shown on the left. The other diagrams illustrate various methods of indicating the anode and cathode leads of actual components, all of which are loosely based on the circuit symbol

short of perfection. An ideal diode should have no resistance in the forward direction when conducting a current, or failing that it should at least have a very low and consistent resistance that did not vary with changes in the current flow. In the reverse direction when blocking any current flow it should have an infinite resistance and no current should flow.

Modern diodes come close to perfection when blocking a current flow, and any leakage current is usually far too low to be of any consequence. Things are far less satisfactory in the forward direction, with a typical silicon diode requiring about 0.5 to 0.6V to be applied before it will start to conduct significantly. In other words, there is a voltage drop of about half a volt through the device, and at higher currents the voltage loss increases a little.

With small voltages, an ordinary silicon diode will fail to operate at all, and will block a significant current flow in either direction! Another drawback of this voltage drop is that it produces a significant power loss when operating at high currents. This loss of power is unlikely to be large enough to be a major problem *per se*, but it does mean that a few watts of power can be dissipated in the component when passing currents of a few amps. As mentioned previously, this will usually require a certain amount of heatsinking in order to prevent overheating.

Avoiding the drop

There are alternatives to ordinary silicon diodes, and one of these is the humble germanium diode. The original semiconductor diodes and transistors were based on chips of germanium rather than silicon. Germanium devices do not work very well by modern standards, and are now largely obsolete. However, some germanium diodes are still available, and they do actually work much better than the silicon variety when low forward voltages are involved. They are suitable for small-signal applications such as the demodulators in AM radios, where silicon diodes fail to work at all. (My fellow columnist Jake Rothman has been discussing Germanium devices in his recent *Audio Out* articles.)

Germanium diodes have a couple of drawbacks, and one of these is much higher leakage currents when a reverse voltage is applied. The reverse resistance of a silicon diode is so high that it cannot be measured with an ordinary multimeter, and any reverse current flow is far too low to be of significance. The reverse resistance of a germanium diode will often register when checked with a multimeter, and might not even require the use of the highest resistance range. Although a reverse resistance that could be a 100kΩ or less does not look good on paper, it is still much higher than the forward resistance, and is adequate to provide good results in many real-world applications.

Another problem with germanium devices is that they are more vulnerable to heat damage than the silicon types we are used to using. Extra care has to be taken when soldering germanium diodes into place. A small clip-on gadget called a heat-shunt is helpful when dealing with components that are very vulnerable to heat damage, or if you are not confident about your ability to complete soldered joints quickly. The idea is for this to be clipped onto the lead of a component before soldering it to the circuit board. Some of the heat flowing along the lead-out wire goes into the heat-shunt, which therefore helps to keep the component 'cool'. A small crocodile clip works quite well in this role if you do not have a proper heat-shunt (Fig.2).

Schottky diodes/rectifiers

Schottky diodes and rectifiers could be regarded as a modern alternative to germanium devices, giving a forward voltage drop that is typically about one third of that provided by an ordinary silicon component. However, their forward transfer characteristic is different to that of germanium diodes, and the latter are still preferable for some applications. Schottky diodes and rectifiers are generally preferred in applications that involve high frequencies or high-speed switching, such as switch-mode power supplies. The lower forward voltage drop also makes them preferable when high currents are involved, since they produce less wasted power and consequent heat.

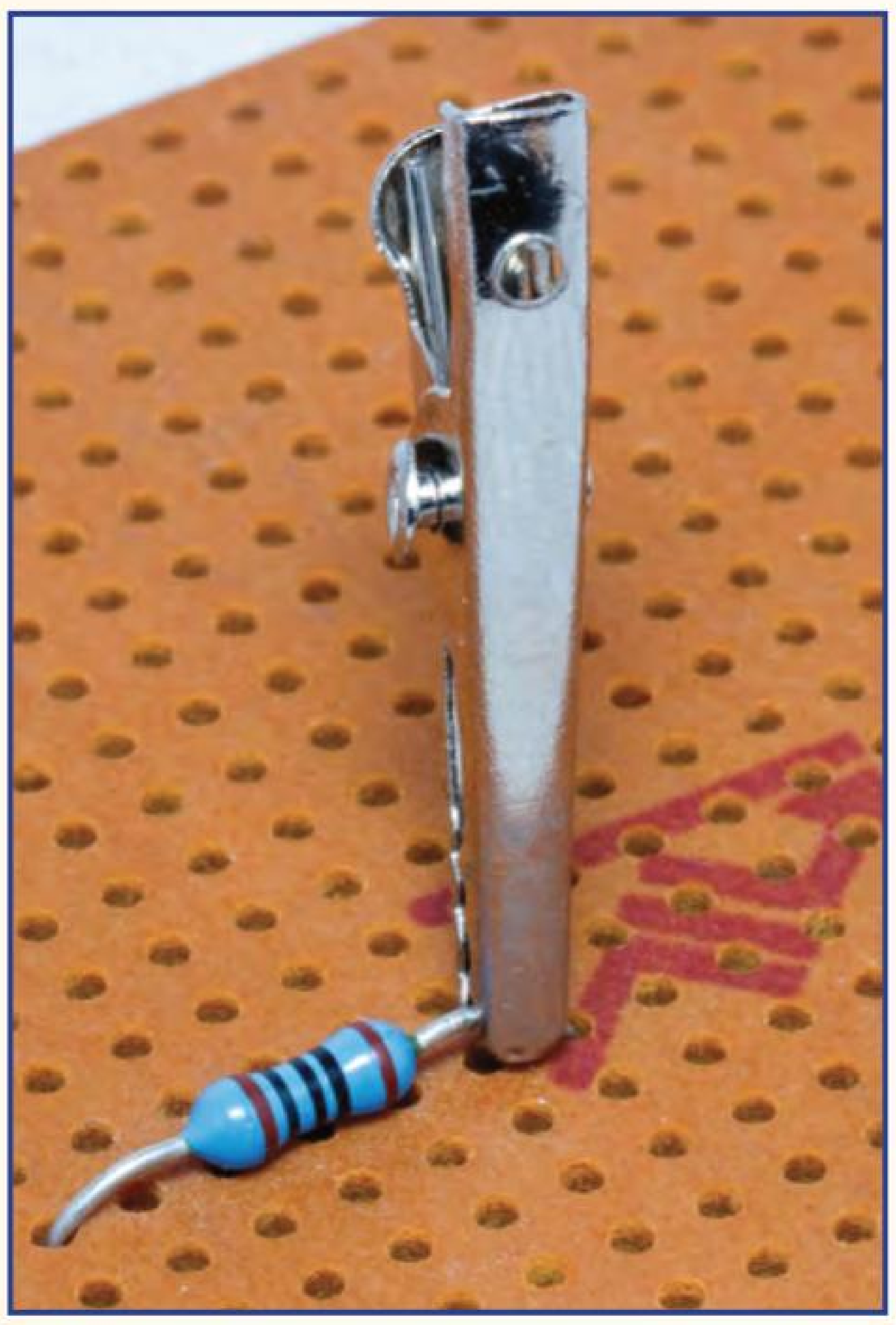
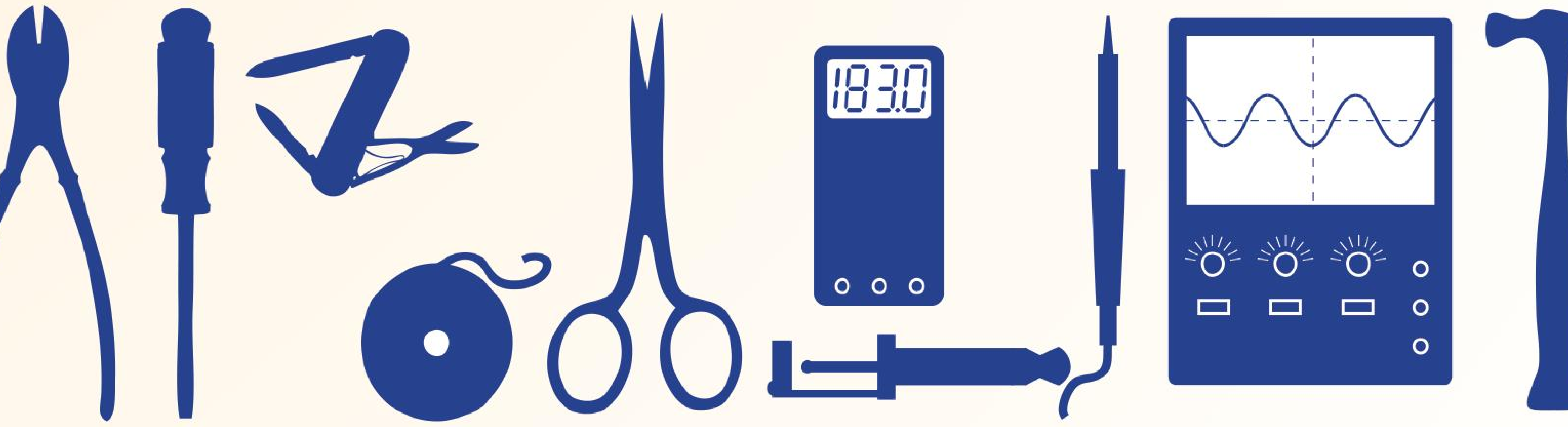


Fig.2. A crocodile clip can be used as a simple but effective alternative to a proper heat-shunt. It diverts some of the heat away from the component when it is being soldered to the circuit board. This is particularly important for soldering germanium devices

Zener diodes

There are a few types of specialised diodes where it is not actually the electronic valve action of the component that is of interest. Instead, some other aspect of a simple semiconductor junction is exploited, and in the case of a Zener diode it is the reverse breakdown voltage. For a normal diode this voltage is quite high, and many small diodes can operate with reverse potentials of 100V or more. A Zener diode is designed to have a relatively low reverse-breakdown voltage. In fact, some are designed to break down with a reverse voltage of just a few volts.

The point of this is that it enables Zener diodes to be used in simple voltage stabiliser circuits. They are used as basic shunt stabilisers in



conjunction with a load resistor. Although taken beyond the point where it breaks down and ceases to block a current flow, the device is not damaged because the resistor prevents an excessive current from flowing. Semiconductors usually come to grief when excessive voltages are involved, but this is one exception.

The last three digits of the type number usually indicate the operating voltage of a Zener diode. A BZY88C5V6 for example, is a 5.6V Zener diode. Although they were once a common feature in electronic circuits, Zener diodes are little used in modern designs. This is simply because modern technology has progressed, and integrated circuit voltage stabilisers now do a much better job for about the same cost.

Varicaps

A variable capacitance diode, or 'varicap' as it is also known, is another type of diode where the electronic valve action is not important. If anything, it is more of a hindrance than an asset in this application. A diode exhibits a small amount of capacitance, which is not normally desirable but is unavoidable. A varicap diode makes a virtue of a necessity by exploiting the fact that this self-capacitance can be altered by feeding the component with a variable reverse voltage. The fact that diode action as well as a variable capacitance is provided can be problematic. In practice, varicaps are normally used in pairs in a circuit that nullifies any potential problems. Some of these components are in the form of single diodes in normal diode encapsulations – but internally they often house pairs or even several pairs in special encapsulations. When specified, a project description should include connection details for any non-standard components of this type.

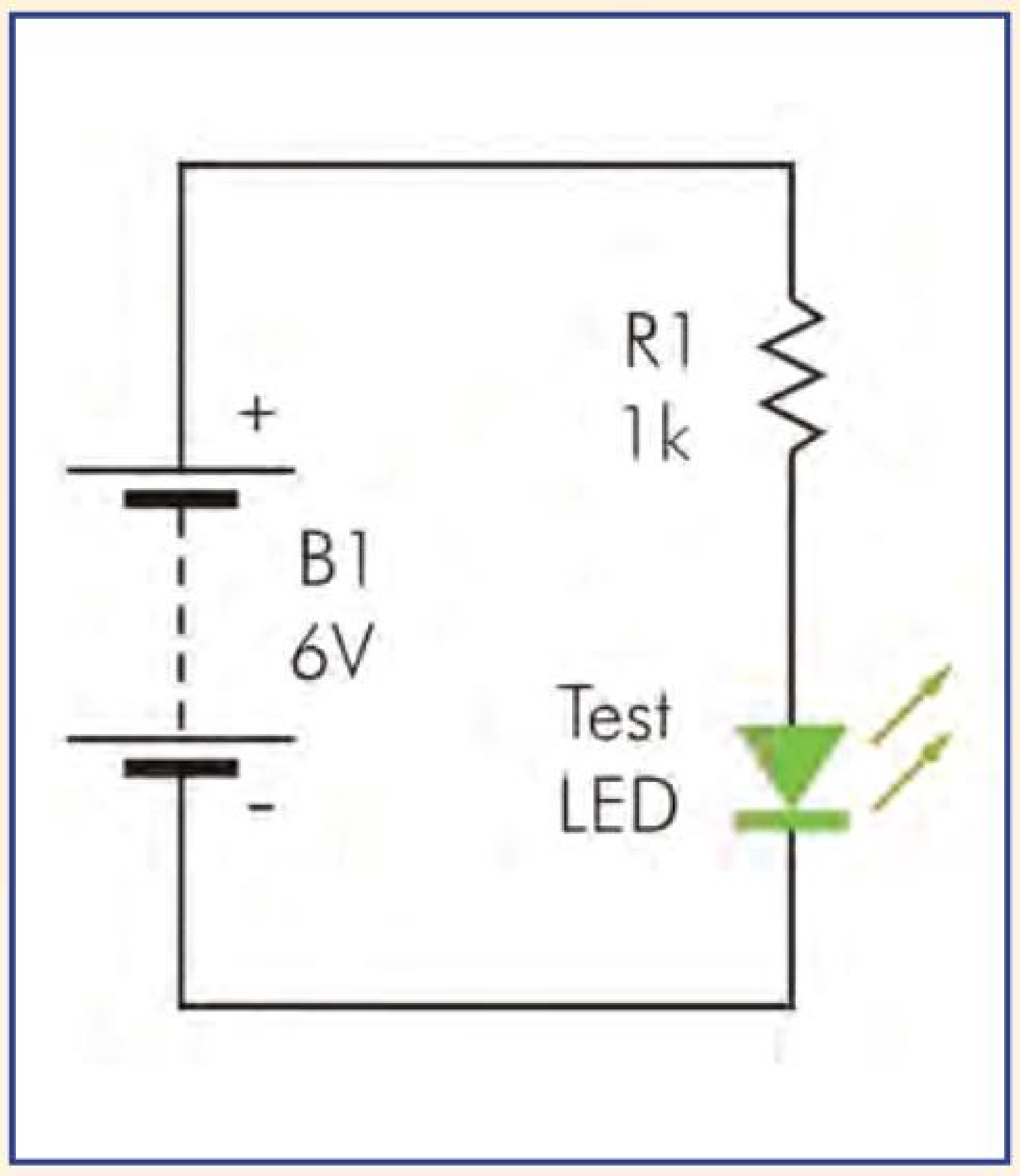


Fig.3. The LED will light up when connected as shown here, but it will not work if it is connected with the opposite polarity. It is essential to include the series current-limiting resistor to protect the LED from excessive current

Seeing the light

The fact that an LED (light-emitting diode) provides a diode action is once again, and fairly obviously, not the reason it's used. However, it is important to keep in mind that an LED is a genuine diode, and it will only light up if it is connected to the power source with the correct polarity. Fitting one with the wrong polarity is unlike to cause any damage, but it will definitely not produce any light.

Various methods of indicating the polarity of a LED are in common use, but by far the most popular method is to have the cathode lead-out wire a few millimetres shorter than the anode lead. Unfortunately, this method is not fully standardised, and while the vast majority of LEDs do conform to this system, a minority either do things the other way round, or simply have two lead-out wires of equal length. There is another common method, which can be used instead of, or in addition to the shorter cathode lead. This is to have the case flattened slightly next to the cathode lead. However, there is again no absolute guarantee that any flattening will indicate the cathode lead, or that it will be present at all. These days, LEDs come in a wide variety of different shapes and sizes, which further complicates matters. In fact, the normal methods of polarity indication might not even be relevant with more exotic LEDs.

Although an LED should not come to any harm if it is connected with the wrong polarity, it is better to get things right first time. Rectifying mistakes can easily result in damage to components and/or the circuit board. Most test meters have a diode checking facility, but many of these are not suitable for determining the polarity of LEDs. The problem stems from the fact that LEDs are made using gallium arsenide rather than silicon, which gives them electrical characteristics that are different to those of silicon diodes. In particular, they require a forward potential of about 2V before they will begin to conduct, which is much higher than the 0.5 to 0.6V required by a silicon diode. This seems to be higher than the test voltage used by some multimeters for diode and resistance checks. The reverse breakdown voltage of an LED is usually quite low, and a device will conduct in both directions if a higher test voltage is used.

It is not difficult to make a simple LED checking circuit, and something as basic as the one shown in Fig.3 will suffice. Try the test LED with both polarities, and when it lights up it has the polarity shown in Fig.3. Any battery having a voltage in the range 3 to 12V can be used. Do not be tempted to connect an LED directly to the power source. Without the current-limiting series resistor it will flash briefly and then be almost instantly destroyed.

Bridge building

Rectifiers are often used in bridge circuits where they process the AC signal from a transformer to produce a full-wave rectified DC signal. A bridge rectifier can be made from four individual rectifiers, or it can be bought as a single component that has four rectifiers connected in the appropriate fashion. Their physical form varies somewhat from one type to another, but bridge rectifiers are usually squares or discs of plastic with four thick lead-out wires. The higher-current types often have a hole in the middle so that they can be bolted to a metal heatsink.

Any bridge rectifier should have markings that clearly indicate the correct method of connection. Some have a circuit diagram marked on or moulded into the case. Probably the more common method these days is to have the AC input leads marked 'AC' or with '~' signs (Fig.4). The leads that carry the DC outputs are marked with '+' and '–' signs. As always with rectifiers, or any components that operate with relatively high power levels, do not rely on guesswork or trial and error. Getting it wrong can cause costly damage and could be dangerous.

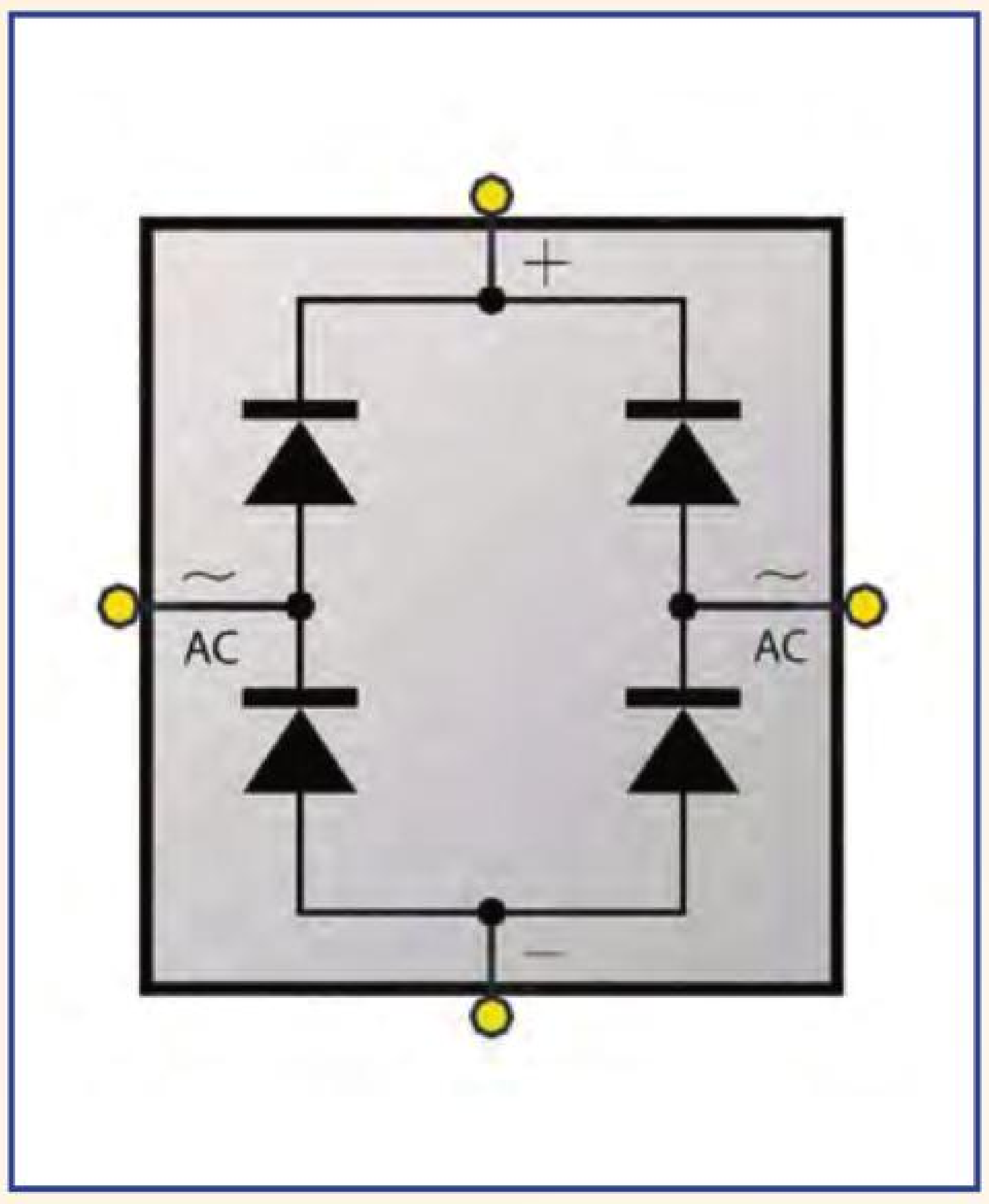


Fig.4. A bridge rectifier is often used in power supply circuits to convert an AC input signal to a full-wave rectified DC output. The two 'AC' or '~' leads can be connected to the AC input signal either way round

NET WORK

by Alan Winstanley

The Battle of Mobigeddon

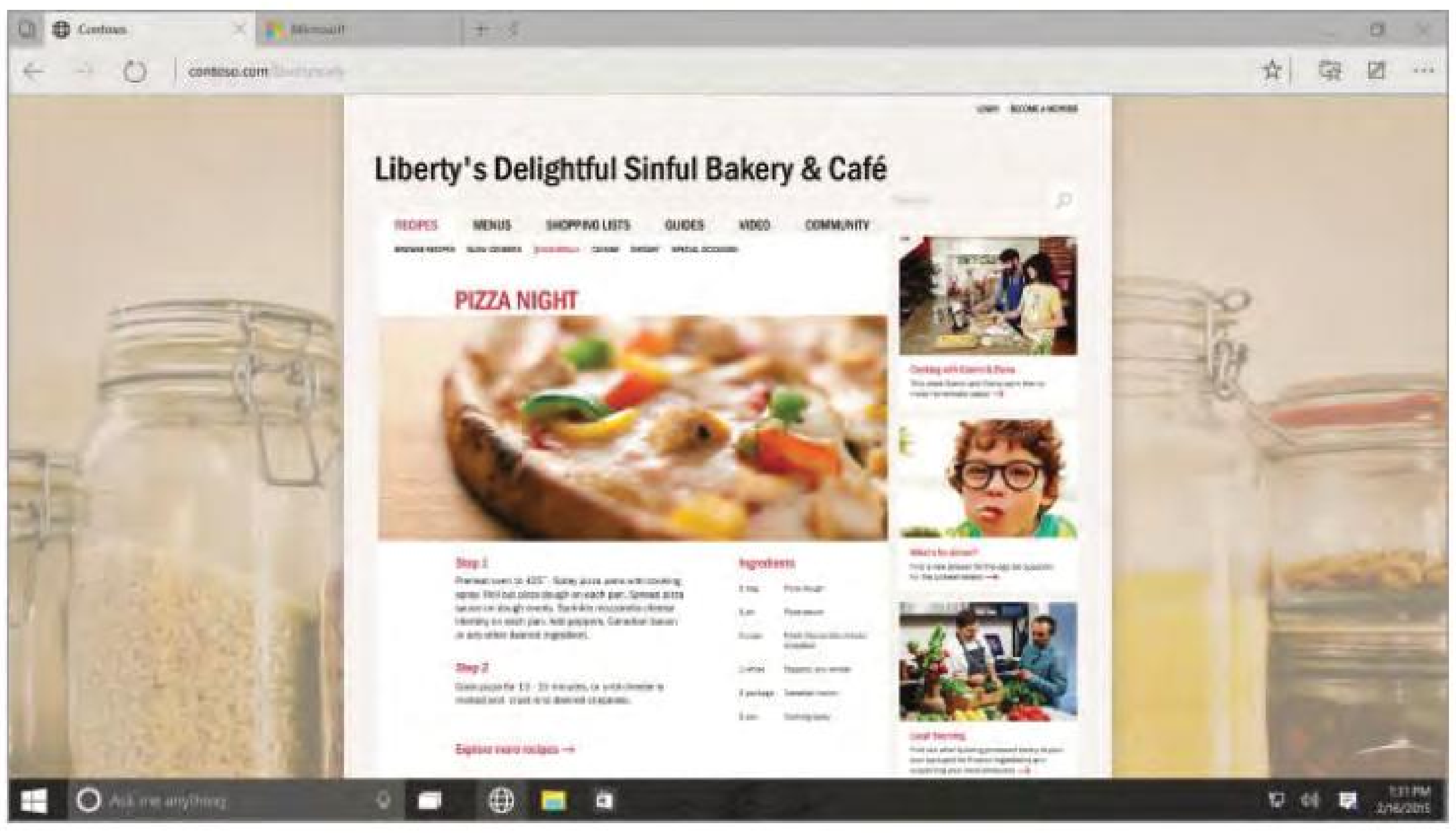
THIS month kicks off with the announcement from Google of a major update to the search engine's algorithms. The latest iteration was quickly dubbed 'Mobigeddon', which reflected Google's efforts to skew mobile search results in favour of mobile-friendly websites. Google makes hundreds of calculations on the fly when computing search results, and initially these were dedicated to the quest for accuracy, relevance and the weight (reputation) carried by web links.

The search engine's latest update aims to check that websites look good on a mobile screen such as a tablet or smartphone. Leading-edge web design now embraces the different platforms that visitors use when clicking around, as a lot of surfing is done on mobile devices instead of wide, high-resolution desktop screens. Many web pages can therefore re-arrange themselves to display properly regardless of the user's screen (called responsive web design in the trade). Gone are the days when just web content was king, and websites risk a drastic reduction in search engine visibility if they don't perform well on mobile platforms. If you own a website then it's worth setting up its address in Google Webmaster Tools and tracking any issues that way – more design guidance can be found at: **https://developers.google.com/webmasters/mobile-sites/get-started**.

Microsoft gives browsing the Edge

Many PC users will recognise the constant and onerous need to repair, update and patch key pieces of software – something that comes with every computer package (it's a hidden cost of a system's TCO – 'Total Cost of Ownership'). Latterly, gaping holes and exploits in operating systems and PC software have emerged everywhere, and a steady stream of routine software updates has become a riptide. However, there are no such Microsoft updates for obsolete Windows XP or its elderly and unsafe version of Internet Explorer (use Firefox instead); Microsoft has also withdrawn mainstream support for Windows 7 (see *Net Work*, April 2015). Nevertheless, Windows 7 and 8 updates continue to arrive apace and automatic patching and installing can be configured via the Windows Control Panel or Settings menu. Windows Updates installs patches every few weeks as new threats continue to emerge in this global game of digital cat and mouse.

Anticipation is rising about Windows 10, Microsoft's next-generation operating system, due in the summer, with free updates promised for Windows 7 (hopefully) and Windows 8.1 users. You can register your interest at **http://windows.microsoft.com/en-gb/windows-10/about**. Microsoft's new slimmed-down web browser, now called 'Edge', is part of Windows 10, along with Cortana, their chirpy digital voice recognition assistant. Aping the tablet experience, Edge is cleaner, flatter and arguably a lot blander than its 3D icon-festooned predecessors, though the flat design that is becoming so fashionable is, in my mind, often harder to navigate around as it lacks useful visual cues. Microsoft Edge aims to be more reliable than Internet Explorer ever has been, which can only be good news. IE11 on my Windows 7 PC, running with a near 4GHz quad-core processor, still falls over when accessing a number of websites, and then I have to cut and paste the URL into Firefox. Barely a week goes by without Firefox updating itself, which should be done as soon as the pop-up reminder appears. In last month's column I also walked through various security settings, pointing out that SSL3.0 is best disabled in your browser in favour of TLS1.1 and TLS1.2.



Microsoft's Edge browser is expected to replace Internet Explorer in due course

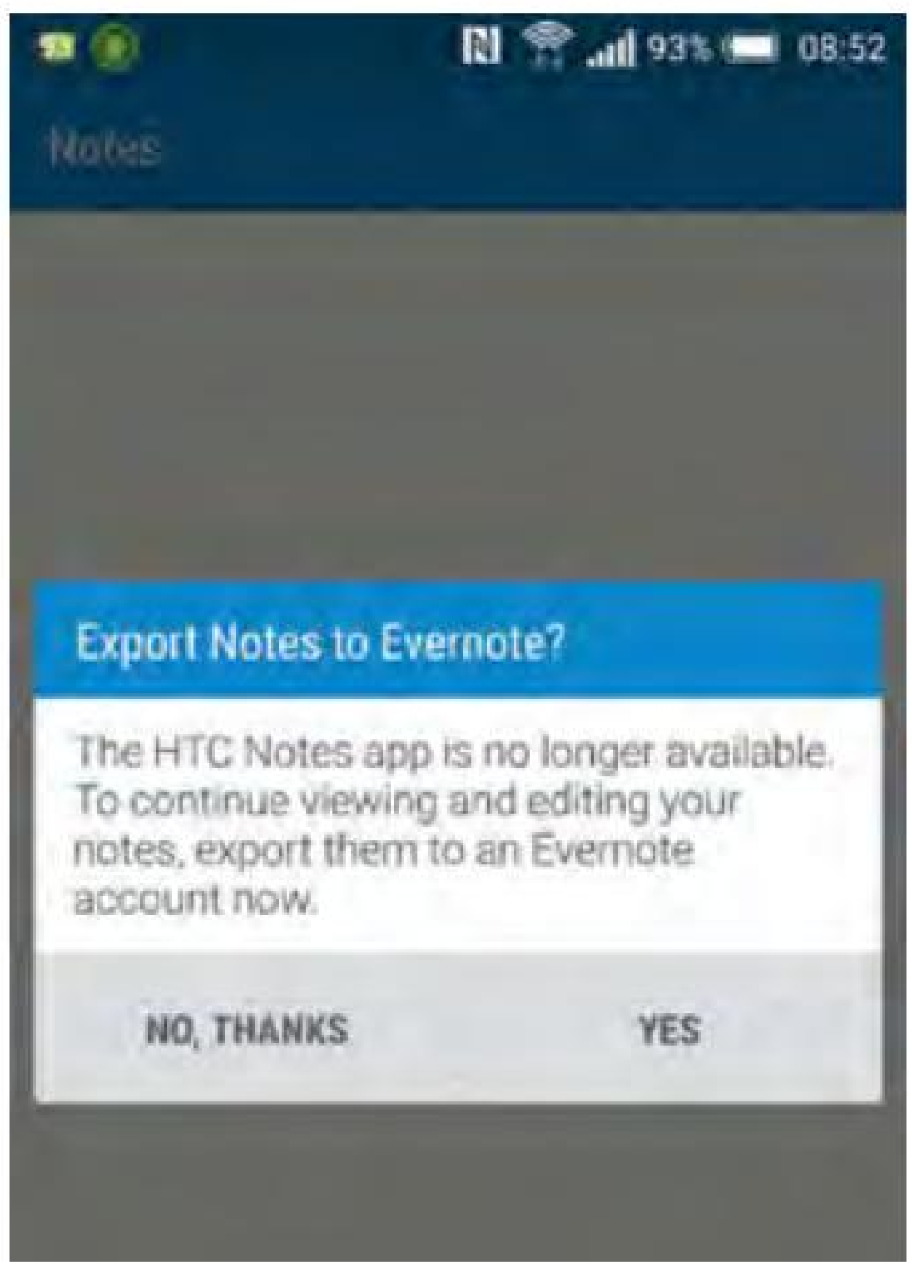
The security firm FireEye claims to have two million virtual machines stationed around the globe that identify threat patterns very rapidly, and in mid-April they reported seeing a limited 'advanced persistent threat' (APT) that exploited zero-day (ie, one that had not yet been patched) vulnerabilities found both in Adobe Flash and Microsoft Windows. It's claimed that the highly targeted attack probably originated from a Russian espionage group. Adobe duly rushed out an update, and Microsoft was working on it (Windows 8 or later is unaffected). Many threats like these circulate in the wild in very obscure locations and individuals would generally have to be very unlucky to suffer any damage; however, as I described last month, one careless mouseclick on a hacked website could result in ransomware such as the infamous Cryptowall locking up all your valuable data and causing critical damage to your system. In short, while some of the risks and threats may sound over-stated, it's always wise to keep software updated, especially Adobe Flash Player and Adobe Reader which head my list of a surfer's most vulnerable and attack-prone programs. Visit **https://get3.adobe.com/flashplayer/update/plugin/**. It is probably best to allow Adobe to automatically download updates, then you can install them when you want – the sooner the better.

Gambling on apps

The advent of the smartphone and tablet triggered a seemingly insatiable demand for 'apps', small programs that can be free to download or cost next to nothing to buy (such as the Torque Pro for Android app that displayed a car's OBD II data on a Bluetooth smartphone, shown in January's edition). Apple's App Store boasts more than one million rigorously-tested apps for its iPhone, iPad or iPod Touch line-up, while Google Play offers Android users more of the same. Amazon also has an Android appstore.

An app seller probably craves nothing more than hotwiring a direct link to a customer's current account or charge card, so that buying goods, apps or in-app add-ons becomes a single-click, painless and seamless experience completed at the user's maximum point of interest. Some games apps have in-store purchases such as power-ups that enable developers to make more money from players as the game unfolds. As games designers are now realising, the problem with the fickle nature of their target market – one that blips from one product to the next – is that it's never long before something else comes along, so people soon get bored and move onto the next big idea. Developers now give away their games for free and rely on revenue generated by 'bookings' (in-app purchases). The general trend in Britain is moving towards gambling, as our TV screens prove, with commercials for online casinos and bingo overwhelming those for Candy Crush Saga.

A typical smartphone may host several dozen apps – recently, some plumbers who fixed my central heating used a bubble level app on their iPhone when installing new pipework! – and sometimes an OS update like Android's Lollipop 5 can affect the compatibility of pre-installed apps. The pressure is then on the developers to upgrade them. The author's HTC smartphone spends an inordinately long time stuck in a continual cycle of app updates, but at least the process is usually smooth and troublefree, although some apps such as HTC Notes are then dropped altogether. Even Wi-Fi digital cameras such as some Sony digicams can now run apps that provide extra features. Some apps seem almost more trouble than they are worth, though: for example, I found the eBay app on an Android tablet had serious syncing problems as it streamed some hopelessly wrong information about unsold items (which had in fact sold), or new bid alerts that had since been outbid anyway, causing an awful lot of confusion at the time.



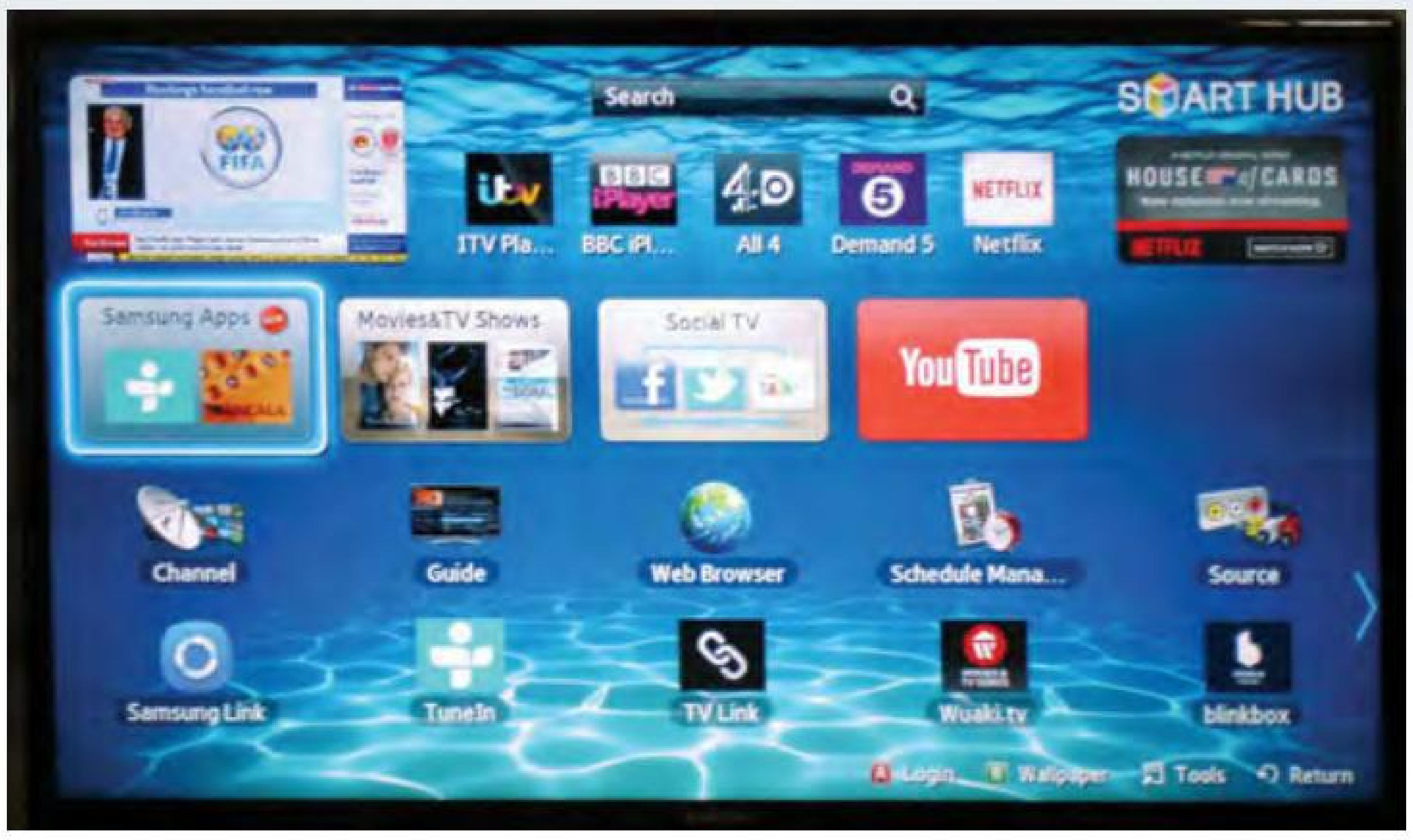
Export Notes to Evernote?

The HTC Notes app is no longer available. To continue viewing and editing your notes, export them to an Evernote account now.

The HTC Notes app no longer works and users are migrated to Evernotes instead

Service closure

A more worrying trend is the closure of dedicated network services that leaves end-users out on a limb, owning a piece of compromised hardware that no longer works as originally intended. For example, the author's Samsung Smart TV arrived with some Samsung apps pre-installed in its web-connected Smart Hub platform, but from day one trends started to emerge with services gradually being shut down. Samsung's Family Story, a photo sharing and messaging app, complete with dedicated hot-key on the TV's remote control, soon closed and is now tablet and mobile-friendly only. More recently, Samsung's pre-installed Fitness and Kids apps were killed off, but at least the TV is still compatible with Youtube. Many readers use a smart TV to enjoy catch-up services like BBC iPlayer, or to access Netflix, Wuaki TV or Amazon's Instant Video movies – if their smart TV is compatible – and of course a pre-configured click-through to your bank account speeds the process along.



Several dedicated Samsung Smart TV apps have shut down and been removed; Kids and Fitness replaced by a clumsy Youtube button (photo: author)

Google, the owner of YouTube, has also been hard at work. From April this year, YouTube stopped working on certain network devices manufactured in 2012 and earlier, including Sony and Panasonic TVs and Blu-ray Discs, older Apple iOS devices and devices running older versions of Google TV. Compatible brands are listed at: **http://www.youtube.com/yt/devices**. If your browser supports Flash or HTML5 then you may still be in luck, otherwise you will have to strike another app off your hardware's compatibility list. YouTube is also said to be toying with the idea of a subscription-based service that would be ad free. Looking ahead, Sony has announced its next generation of 4K TVs will be Android-powered, reflecting an emerging trend in TV network connectivity.

Life span

End-users can be forgiven for wondering how long their favourite apps and hardware will work in the months and years ahead. The abrupt ending of services also hit some Internet radio channels: in February this year, BBC Radio dropped the WMA (Windows Media Audio) format used for its streaming radio service. The BBC stated that WMA was too costly, restrictive and out of date, so it has adopted SHOUTcast MP3 for Listen Again radio. This crippled the ability of some Internet radios, such as the original Pure Evoke Flow to stream BBC Listen Again radio. However, there are plenty of other radio channels available online, and PC or mobile users can try the **SHOUTcast.com** website and access thousands of Internet-based broadcasters instantly. The SHOUTcast website is typical of the modern, flat, oversimplified and featureless design beloved by tablet users – try to find the 'play' and 'stop' controls! Other sources of streaming radio to try include **TuneIn.com** (apps are available) and Pure Connect (**http://connect.pure.com**).

PURE
EVOKE Flow
PC
18:55
Station not available
Options

Tuned out: PURE's Evoke Flow is no longer compatible with WMA-based BBC Listen Again radio (photo: author)

British Airways

The British Airways app makes it even easier to keep up to date with all your latest flight information. See your flight status, access scheduled or estimated departure times, and even view the latest weather information at your destination, all at a glance. You can also set up the Apple Watch app to receive your up-to-the-minute flight gate status direct to your wrist.

Apple's new Watch pairs to an iPhone and uses apps to summarise information; some features can function without an iPhone

The Apple of my eye (wrist)

As a sign of technology heading our way, Apple's new and much-hyped Apple Watch brings the power of mobile apps to the owner's wrist. Apple's first example of wearable hardware is a cut-down control panel that connects wirelessly to the owner's iPhone. It's an attractive piece of touch-screen engineering that literally gives the traditional watch crown a new twist – as a navigation tool. Apps that harness the potential of the Apple Watch are already on the way, including, for example, Delta, United and British Airways and EasyJet apps: these enable passengers to track key information about their flight, including departure time, boarding gate and status and the weather at the destination, all beamed directly to the wrist-mounted display. Even without an iPhone, tasks such as displaying boarding passes may still be possible. Britain's National Rail Enquiries promises a Watch app in May 2015, and health and fitness apps that use the watch's photodiode-based heartrate monitoring sensors will complement it perfectly. More details of the tech behind the Apple watch are at: **https://www.apple.com/uk/watch/technology/**

Tide
Start
Stop
Cottons
Minim

Amazon Dash Button re-orders deliveries of consumables with a single press

Amazon is releasing a shopping app for Apple Watch that utilises voice recognition to search for products, and 1-Click ordering allows for a seamless 'buy'. One Apple Watch reviewer successfully added a $343 Xbox One to his **Amazon.com** wish list, but due to a careless finger-tap he then accidentally bought it using the app's 1-Click button: he had to scramble online to cancel his order. Amazon US is also innovating with Amazon DRS ('dash replenishment service') – a way for consumers to receive routine top-ups of consumer goods such as washing powder, water filters or razor blades. Amazon's DRS systems could arrive pre-installed in appliances like Whirlpool washing machines and Brother inkjet printers, or separate stick-on 'Dash buttons' can be supplied that connect via Wi-Fi. A button press sends a top-up requisition to Amazon and goods are duly delivered (happily, subsequent button presses are ignored). The day of the shopping list may be numbered, as some 275 household products are available this way so far, but the service is invitation-only for now. Apple's Watch and Amazon Dash are signs of things to come, and ever-closer network integration like this is just around the corner.

You can email the author at **alan@epemag.demon.co.uk**

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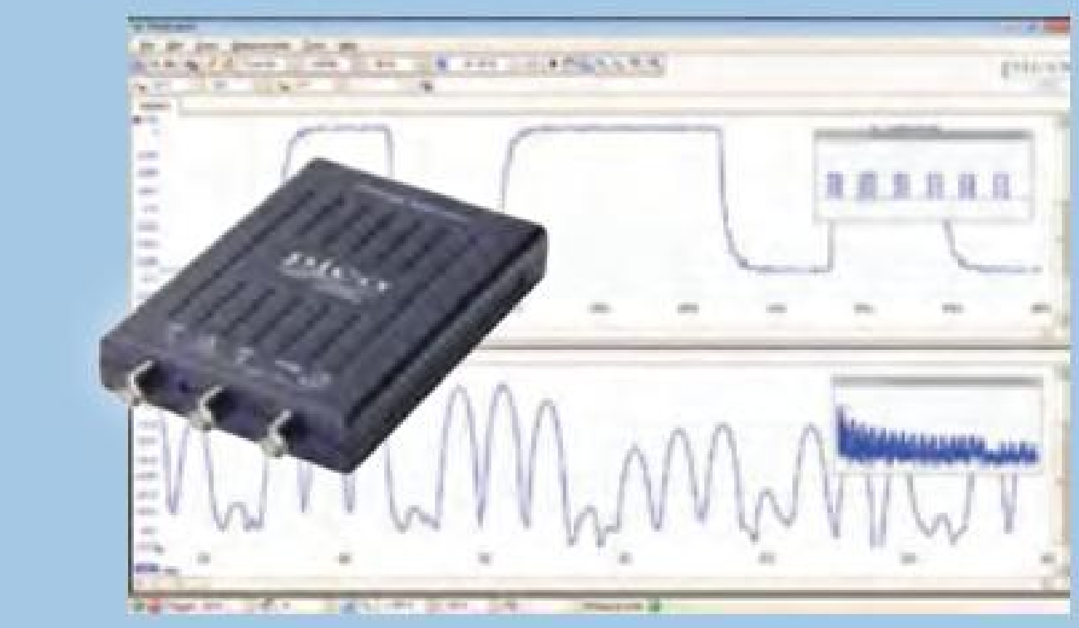

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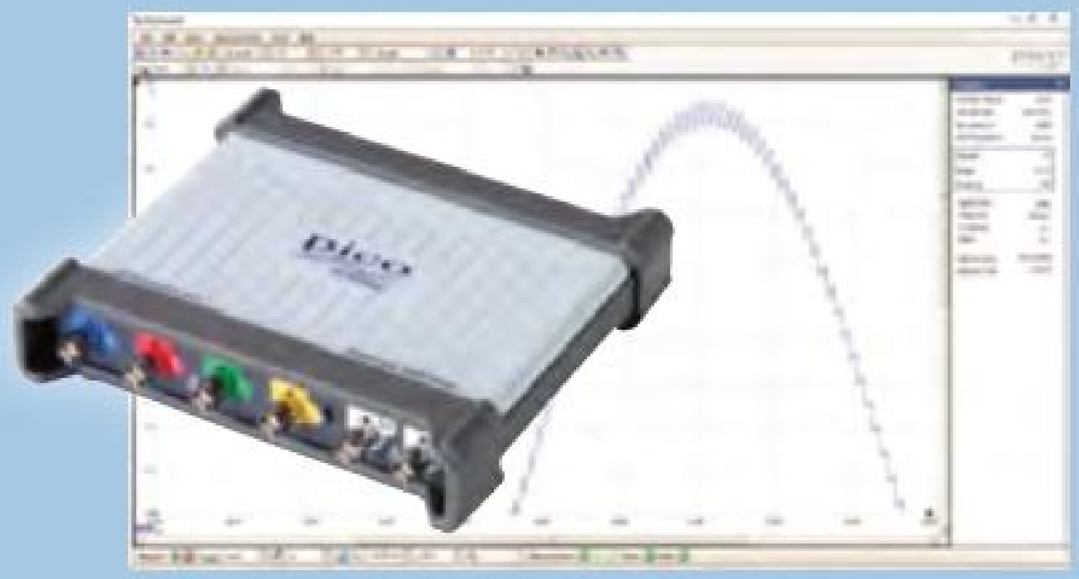

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PIC n' Mix

Mike Hibbett

Our periodic column for PIC programming enlightenment

Simple PIC-based 'scope

WE'VE been adding individual features to our PIC18F development board over the past few months, now it's time to put it to work in a practical application – a simple, useful oscilloscope. We are not going to be covering the design of the input signal conditioning; that would go beyond the scope of this column. However, it will be able to display signals that range between 0V and 3.3V, to match the input range of the PIC's ADC.

This will be an interesting journey. It's the first time we have attempted to create a digital oscilloscope (or indeed, *any* oscilloscope) and so there could be a number of unknown obstacles or limitations along the way.

Let's start by defining the requirements of what we would like to achieve:

- Signals must be in the range 0V to 3.3V; no amplification or attenuation will be provided (although these circuits could be added later)
- A single analogue input to be supported
- Trace to be shown on the 2.2-inch LCD module
- At least 8-bit sample resolution
- A 'single shot' capture trigger to be provided, based on a variable voltage trigger threshold
- Timebase to be selectable, up to the maximum rate supported by the processor's ADC module.

While extra features could be added later, that final specification will be a hard limit. A quick look at the datasheet shows that the fastest acquisition rate is a paltry 100kHz; this is not going to replace your expensive oscilloscope. It may find some practical uses, however, for monitoring audio or very slow serial bus interfaces. We already have one use in mind, which we will cover next month if the project is a success. Although it won't be terribly useful, it should be fun to create a DIY pocketable, battery-powered oscilloscope.

Fitting to the display

Unlike an analogue oscilloscope, our display is pixel based, and so the display module defines the number of sample points we can show and the resolution of those samples.

The ADC module has 10-bit resolution at 100kHz, but we will truncate that down to less than 8 bits because the display can only show 230 pixels vertically, and some of that space is taken up by labels for the axis. Horizontally, we can display up to 320 pixels, which means we are looking to buffer up to 320-bytes-worth of sample readings.

We will acquire a screen full of data first, and then display it. At 100kHz that takes 3ms, but at lower timebase periods it can be many seconds. At the faster sample rates it will be better to acquire the data in one go and then display them, as this avoids the effect of noise that would be introduced by communicating with the display while acquiring samples. At very slow sample rates, such as once per second, it makes sense to change to a different strategy and display each sample as it is acquired. We will leave that second approach for another day, but it could be incorporated easily.

Displaying the labels for the trace's vertical and horizontal axis scale removes 11 pixels from the bottom and the left hand side, giving us an effective drawing area of 308 by 228 pixels. So our strategy will be to take 308 samples, then translate them from 0-1023 to 0-227, adding 11 to give the correct vertical pixel offset. The easiest technique to do this would be to multiply each sample by (227/1023) or 0.22, but this would require the use of floating point maths – which would slow the code down significantly. Instead, we look for a close approximation using integer maths. 2 divided by 9 is 0.222, so we take the ADC sample, multiply it by 2 and then divide the result by 9. Nice and simple, especially as multiplying by 2 is the same as a single left-shift; a single instruction on the PIC microcontroller, so very fast.

Timebase

The timebase is the duration of the signal displayed on the oscilloscope. It is normally quoted in seconds (or milliseconds, or microseconds) per division, with each division being marked on the screen as a thin vertical mark. Each division shown on an oscilloscope display is further subdivided with five smaller divisions to help with estimating the duration of displayed signals. On an 'old-school' oscilloscope this is physically marked on the display glass; modern oscilloscopes display it electronically – we will do the same.

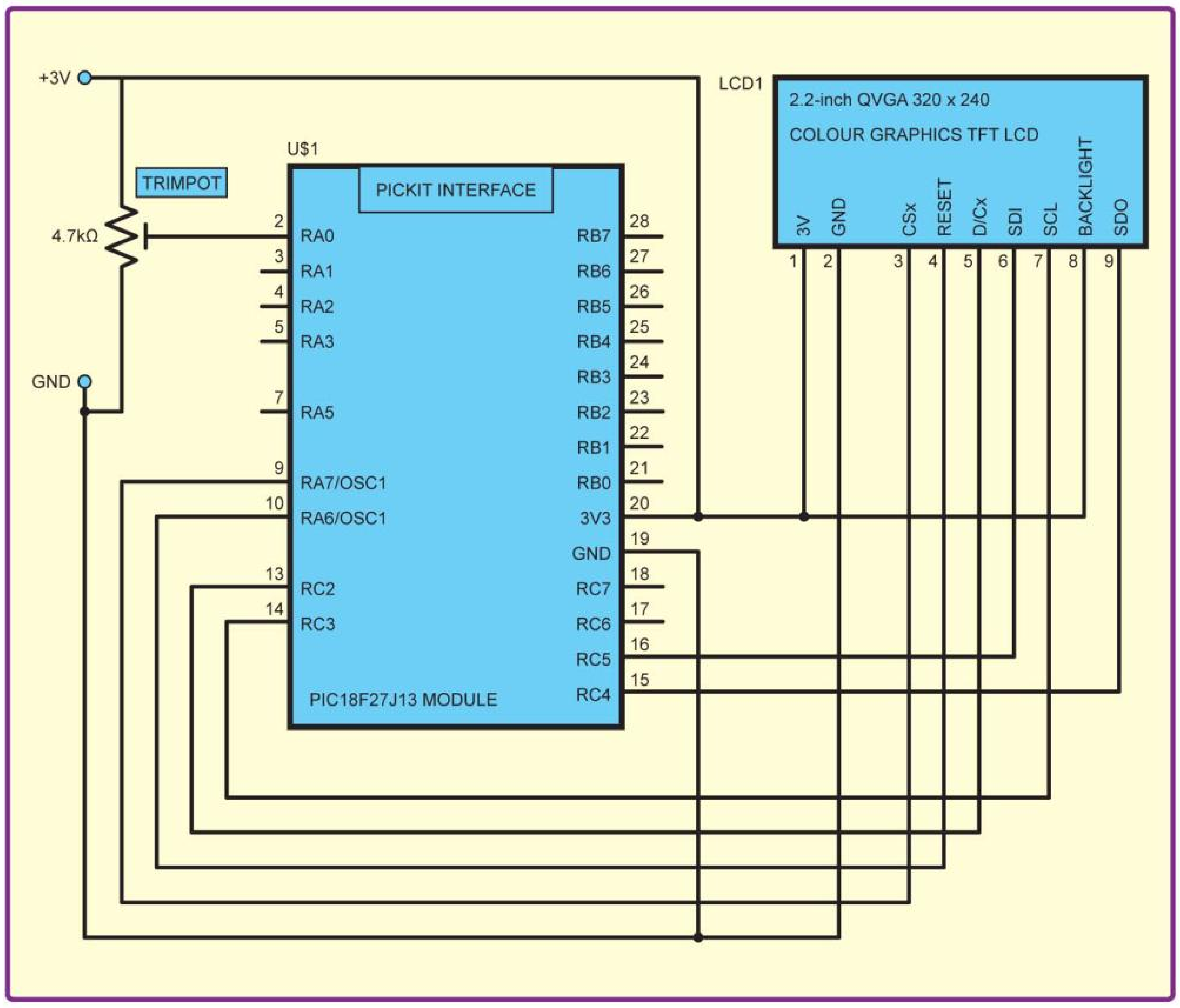

Fig.1. Oscilloscope PIC schematic

ADC sampling

We already support ADC measurements using an interrupt to detect the conversion completion; however, for this project we need to generate the 'start conversion' request from a re-triggering timer, which we allow to run for 308 samples.

This is where things start to get complicated. We need to configure the ADC to perform a conversion, but also a timer to start the conversion. The timer needs to re-trigger automatically so that timing is accurate.

The ADC module provides for a 'Special Event Trigger' to start the conversion. This signal comes from one of the capture-compare modules, which itself needs to be tied to a timer. So that's three different modules that all need to work together. All three need to be correctly configured or nothing will happen, which will make debugging difficult if things go wrong. So let's progress slowly, taking it one step at a time.

We start by working out the ADC parameters. When we last did this, we ran with default-recommended settings because we were not concerned about the time it takes to convert. On more careful examination, this time we spot that the ADC module section of the datasheet recommends a maximum of 2.5kΩ source impedance; with a 47kΩ trim-pot we were exceeding that. So we replace it with a 4.7kΩ trim-pot while developing the code and before giving it a real signal (the plan is to feed it audio from a headphone amplifier, or some other audio generator, which will have a very low impedance.) You can see the schematic in Fig.1.

Assuming a worst-case source impedance, the datasheet informs us that we need a minimum of 2.5µs to acquire the sample – that's the time to charge the capacitor inside the chip at the input to the ADC. Following that, the ADC can disconnect the input and convert the voltage on the capacitor. This conversion process takes eleven ADC clock cycles. The time for each ADC clock cycle, referred to as 'TAD', is stated in the 'Electrical characteristics' section of the datasheet as having to be between 0.7µs and 25µs. If set too short, the ADC system will not 'settle' in time to measure properly the actual voltage. Set too long (greater than 25µs in our case) and the charge on the capacitor will decay through internal leakage. It is our responsibility to set the value of TAD through configuration bits in the ADCON1 register, as shown in Fig.2. So we start by choosing a value for the ADCS bits that get us close to, but no lower than, 0.7µs. Our processor clock speed is 48MHz, and with the limited options available we settle on a value of FOSC/64, or 1.33µs. (We could get a faster time by reducing the system clock, but lets run with that option for now. We don't want to compromise the speed with which we update the display.)

This setting gives us an ADC conversion time of 14.67µs.

We now add in the acquisition time, specified by the ACQT bits in ADCON1. These are offered in multiples of TAD, which we have just set to 1.33µs. We need a minimum of 2.5µs, so a setting of `2*TAD` gives 2.67µs. Adding that to the conversion time gives the fastest speed at which we can take samples – 17.3µs, or 57kHz. Good enough for audio, at least, but sadly, nowhere near 100kHz. If we really want to run that fast we would have to lower our processor speed so we can get a TAD time closer to 0.7µs.

Phew – that was hard work! However, the effort was worth it. Looking at the register definitions in the datasheet and referring back to the paragraphs above, this translates to a single line of code:

```
adc_init(ADC_FOSC_64 & ADC_RIGHT_JUST &
         ADC_2_TAD,ADC_CH0 & ADC_INT_OFF &
         ADC_REF_VDD_VSS,0, ADC_0ANA);
```

Special event trigger

Unfortunately, the hard work is not over – we now need to find some way to trigger ADC conversions at regular, accurate intervals if we want our oscilloscope to display the waveform accurately. Remember, the x-axis (horizontal) on the display is *time*, and we need to plot points accurately against that scale. This calls for an automatically re-triggering timer interrupt that re-triggers without program intervention.

The ADC module provides for this with the 'Special Event trigger', a combination of an enhanced capture-compare module (ECCP) and timer. The timer is set to be free running, and the capture-compare module resets the timer when the timer count reaches a value that matches the ECCP's compare register – generating a 'special event trigger' at the same time. You can see the block diagram for this in Fig.3. We are already using (or at least, have allocated) Timer1, so we will select Timer3 as the free-running timer. The choice of enhanced capture-compare module – we have three to choose from – falls to ECCP2. The datasheet is again vague; at one point it says any ECCP module can generate an ADC special event trigger, but the ADC module section of the datasheet makes reference to ECCP2 specifically – so we play it safe and go with that module.

We know our maximum sample rate is around 57kHz, which sets the fastest rate at which we want the timer to trigger at. We now need to calculate a timer clock source to give us that as a minimum, with larger count values giving us a good range of longer timebases (it would be nice to have a timebase in the seconds range, for sampling slowly changing signals.) Can we do that with Timer3? The block diagram for Timer3 is shown in Fig.4, and yes, it is complicated.

ADCON1 A/D Control Register 1

R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
ADFM	ADCAL	ACQT2	ACQT1	ACQT0	ADCS2	ADCS1	ADCS0
bit7							bit 0

bit 7 **ADFM**: A/D Result Format Select bit
1 = Right justified
0 = Left justified

bit 6 **ADCAL**: A/D Calibration bit
1 = Calibrartion is performed on the next A/D conversion
0 = Normal A/D Convertor operation

bit 5-3 **ACQT**<2:0>: A/D Acquisition Time Select bits

111 = 20 TAD
110 = 16 TAD
101 = 12 TAD
100 = 8 TAD
011 = 6 TAD
010 = 4 TAD
001 = 2 TAD
000 = 0 TAD

bit 2-0 **ADCS**<2:0>: A/D Conversion Clock Select bits
110 = FOSC/64
101 = FOSC/16
100 = FOSC/4
011 = FRC (clock derived from A/D RC oscillator)
010 = FOSC/32
001 = FOSC/8
000 = FOSC/2

Fig.2. ADC configuration register

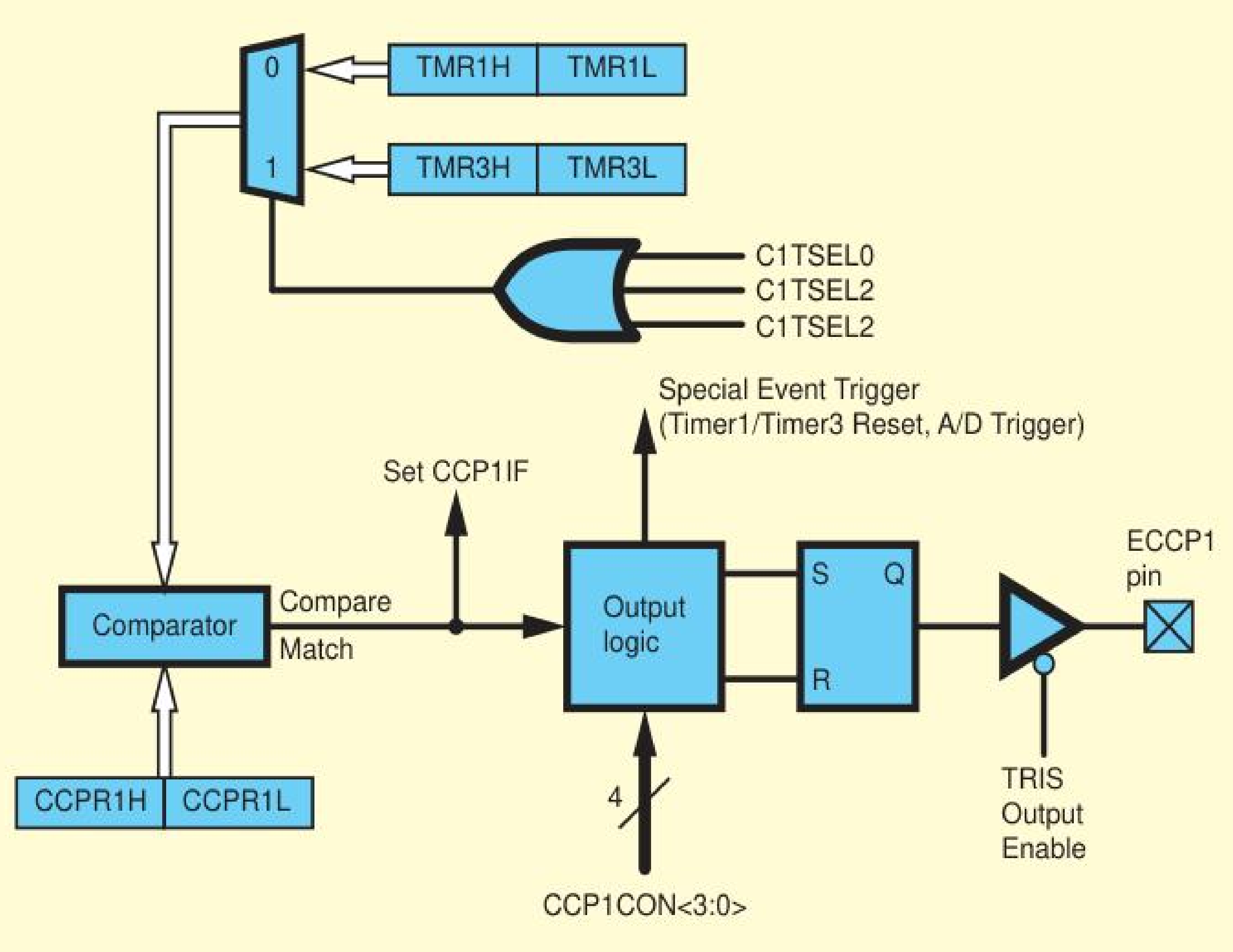

Fig.3. The capture-compare module, coupled with a timer module

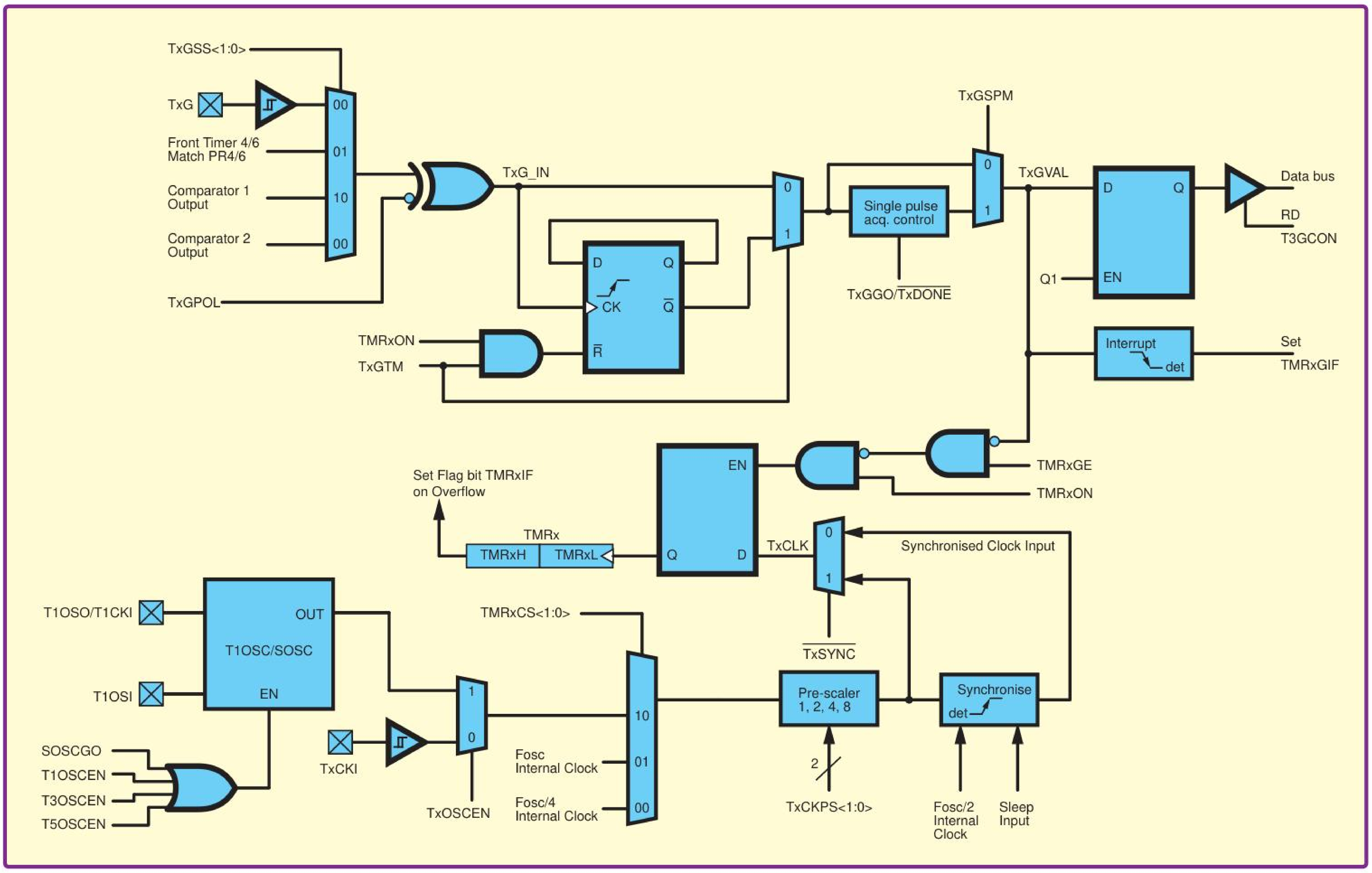
TxGSS<1:0>
TxG
00
01
10
00
Front Timer 4/6 Match PR4/6
Comparator 1 Output
Comparator 2 Output
TxGPOL
TxG_IN
D
Q
CK
Q̄
R̄
TMRxON
TxGTM
0
1
Single pulse acq. control
TxGGO/TxDONE
TxGSPM
0
1
TxGVAL
D
Q
EN
Q1
Data bus
RD
T3GCON
Interrupt
det
Set
TMRxGIF
TMRxGE
TMRxON
EN
Set Flag bit TMRxIF on Overflow
TMRx
TMRxH
TMRxL
Q
D
TxCLK
0
1
Synchronised Clock Input
T1OSO/T1CKI
OUT
T1OSC/SOSC
T1OSI
EN
TMRxCS<1:0>
1
0
10
01
00
TxSYNC
Pre-scaler 1, 2, 4, 8
Synchronise
det
SOSCGO
T1OSCEN
T3OSCEN
T5OSCEN
TxCKI
TxOSCEN
Fosc Internal Clock
Fosc/4 Internal Clock
2
TxCKPS<1:0>
Fosc/2 Internal Clock
Sleep Input

Fig.4. Timer3 block diagram

We take a guess that we need to drop the input clock signal as low as possible, and look to see how we do that on the timer diagram. So we start with the input clock frequency, FOSC, which is 48MHz. Selecting 'div by 4' gives 12MHz. Prescaling by eight gives 1.5MHz. At this input clock frequency, our 57kHz minimum sample time, 17.3µs, is a timer count of 26. That's an acceptable starting point. What is the slowest time we can get? Timer3 is a 16-bit counter, so that is 65535 counts, which equates to 43.69ms. Over a period of 308 samples (the number of samples we can display) this is 13.45s – a very reasonable time period for examining slowly changing signals. And with the option to select the 32kHz clock on Timer1 as the input clock source we could in the future turn this into a *really* long timebase display – up to 1.6 hours! It looks like we have found our ideal timer configuration.

Once again, this preparation – including writing the information down – eases the translation into code. To configure the timer we need to write to just one register, and that line of code is even shorter than for the ADC setup. Here it is:

```
T3CON = 0x33;
```

A quick look at the definition of that register in the datasheet (page 222) will show how the value of 0×33 was arrived at, from the description above.

You may be wondering why we didn't use the functions in the peripheral library to enable this timer as we did for the ADC. The reason is, sadly, that there is an error in the bit field definitions provided by Microchip. This is no issue (other than the time wasted investigating the problem) as the code required is so simple.

With that line of code implemented, the timer is free running, and is not yet triggering our ADC conversion. That job is performed by the ECCP module, which compares the free-running timer's count value against the value in its CCPR2 register. Setting this ECCP module up is easy; just tell it what timer to use, tell it to run in 'Special Event mode', and set the timebase required in the compare register:

```
CCPTMRS0 &= ~0x38; /* Mask C2TSEL bits */

CCPTMRS0 |= 0x08; /* Select TMR3 for ECCP2 */

CCPR2H = 0;

CCPR2L = 26; /* 26 gives minimum sample time of 17us */

CCP2CON = 0x0B; /* Special Event Trigger mode, start */
```

That's it, we are done with configuring automatic ADC sampling. The sampling is running now; all we have to do is enable ADC interrupts, and have some code to handle the samples as the ADC 'conversion complete' interrupt fires.

ADC interrupt

We've already mentioned that as ADC conversions are completed, we scale them from a range of 0-123 to 0-227, to match the pixel placement on this display. We store these values in one of two, 308-entry buffers – we keep the 'previous' set of samples so we can draw over them in the background colour before drawing the newer set of samples. The ADC interrupt 'toggles' between each buffer after each set of 308 samples is collected. Although this consumes an extra 308 bytes of RAM, it does speed up the display update – it's quicker than redrawing the entire display to remove the old trace.

Before implementing the display update code, we have to check that our three-stage setup of the ADC is working. For this, a breakpoint was placed at the end of collecting 308 samples. The code was run up and – yes! the breakpoint was hit almost immediately. Examining the content of the buffer through the debugger revealed a series of values all roughly at the mid-rail level. We hadn't connected the variable resistor to the ADC input, and so the analogue input was floating at the mid-point of the supply rail. All good.

A quick test with the connected variable resistor confirmed the range of the ADC samples and that the limits were being correctly scaled. With that behind us, we can move on to displaying the image.

Displaying the image was the simple task of playing join the dots; we called the LCD_DrawLine primitive to connect from the previous point to the current point. A simple loop completed the basic implementation:

```
while (1) {

while (!samples_ready)

; /* do nothing */

// draw old samples in background colour

// re-draw the graticule

// draw new samples in green

}
```

Why do we re-draw the graticule? It's because the waveforms overwrite it. There may be better ways to display the waveforms to avoid this extra processing step, but that will have to be left as an exercise for another time.

Conclusions

For such a simple device and with only a few hours programming, the oscilloscope is surprisingly functional, if a little raw. You can see the display in Fig.5 – and next month, we will improve its utility.

If you build this, remember that the range of voltages that may be presented to the ADC input is limited – signals must be in the range of 0V to +3.3V, so don't go plugging your headphone output directly into this as the headphone outputs drive below 0V. This issue can be worked around with a diode in series with the input if the driving signal is strong enough.

The circuit will require a regulated 3.3V supply or a set of very fresh batteries, because the LCD module we are using requires this. Coupled with a lithium polymer battery and 3.3V regulator, this would make for the beginning of a useful handheld oscilloscope.

As usual, you can download the source code for this project from this month's project page on the *EPE* website.

Next month

We will finish the project off next month by implementing selectable timebases, trigger level selection and single-shot mode. This will not, however, be the last time we play with DIY oscilloscopes, as we will take a look at a much faster processor later in the year and raise our sample rate into the MHz region.

Not all of Mike's technology tinkering and discussion makes it to print. You can follow the rest of it on Twitter at ***@MikeHibbett****, and from his blog at* ***mjhdesigns.com***

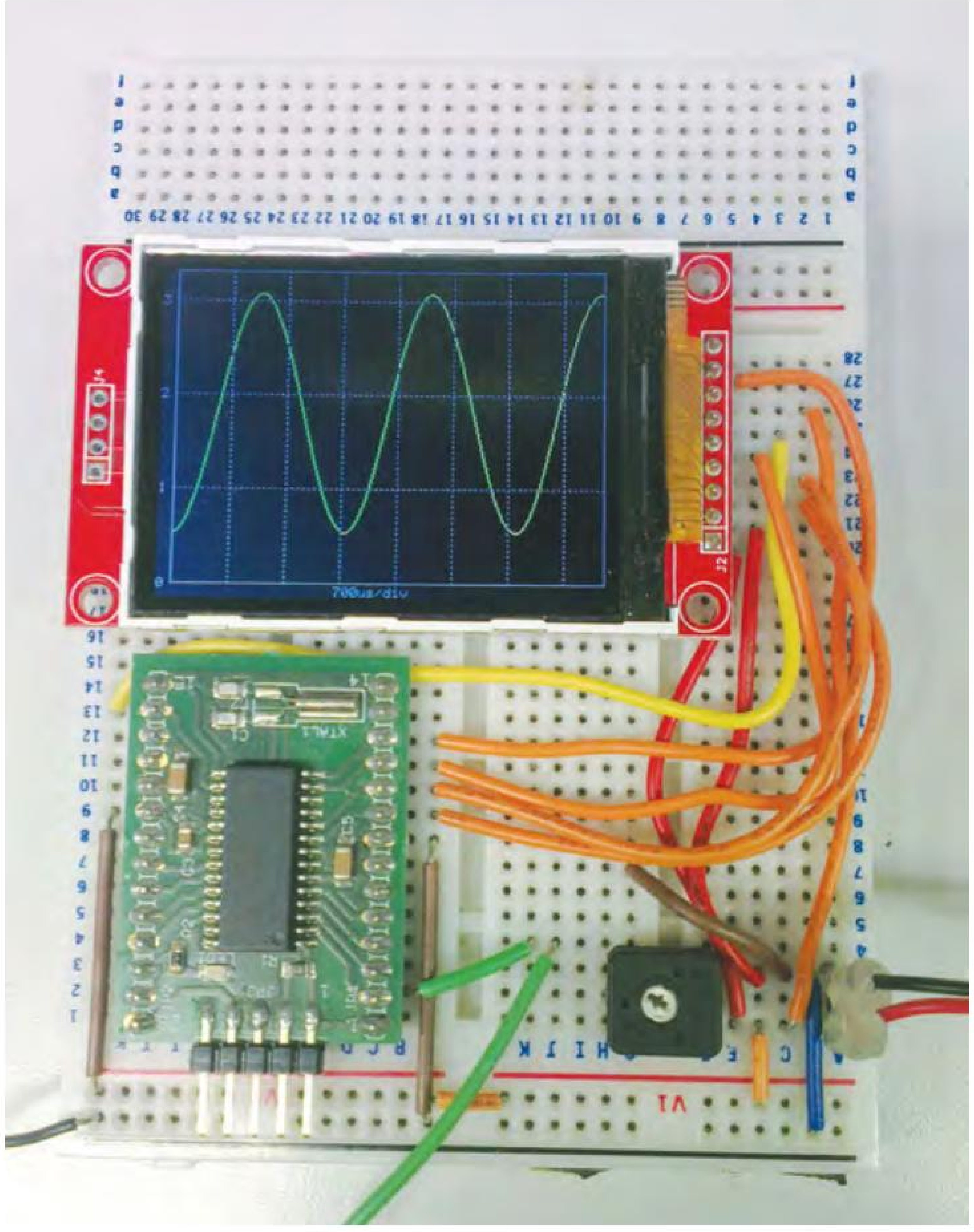

Fig.5. Our PIC-based oscilloscope in use, displaying an audio waveform

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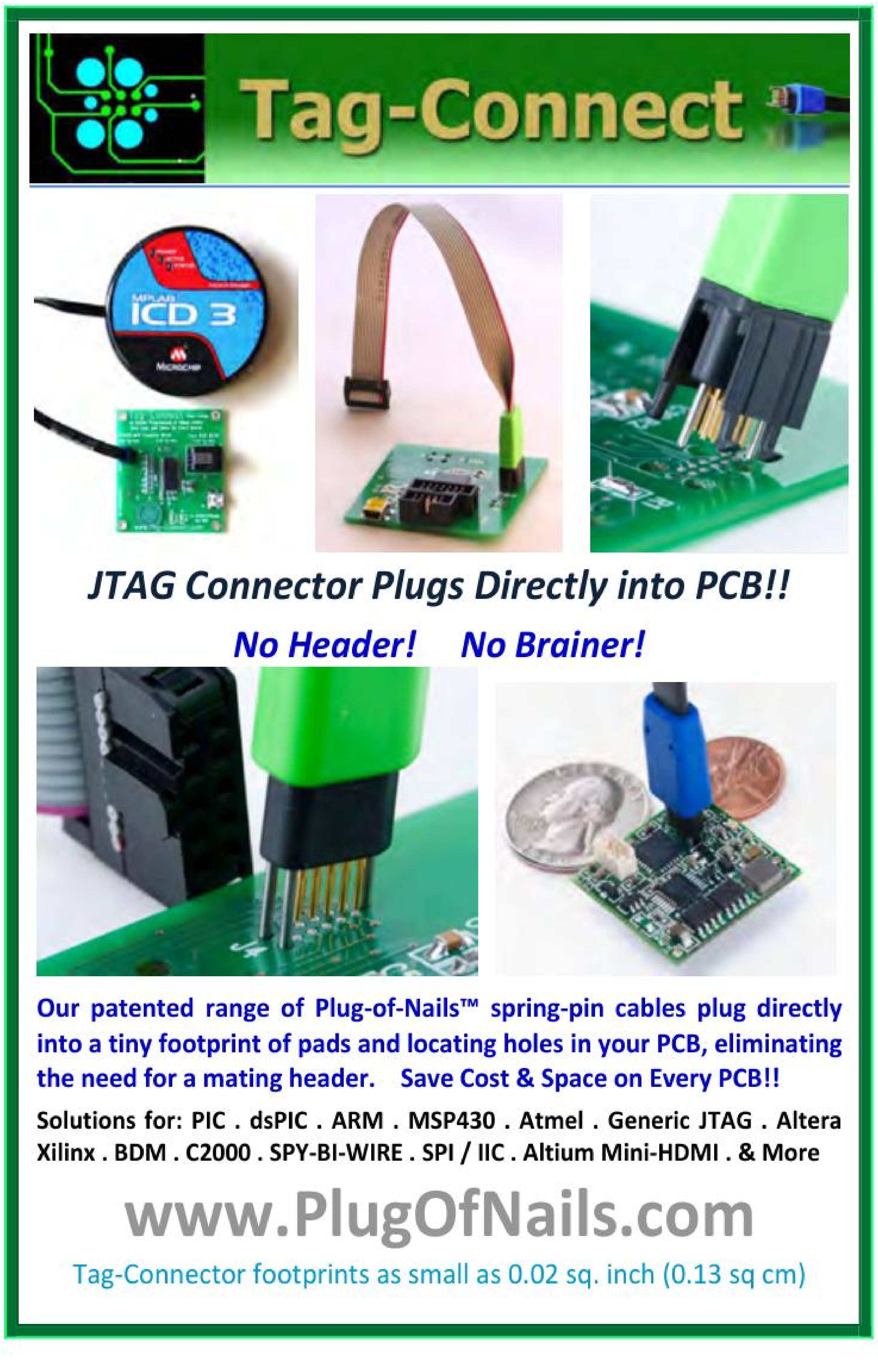
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AUDIO OUT

By Jake Rothman

RIAA equalisation – Part 1

Fig.1. Tracing the groove with a Goldring Elektra moving-magnet cartridge

Old technologies often make comebacks, from steam trains and valve amplifiers to filament light bulbs or Theremins. The reasons are usually to do with their subjective qualities rather than technical efficiency. Vinyl records are no exception, the music stored on an average smart phone would weigh in like a few bags of coal in vinyl format. From its nadir in 2007, when vinyl sales had slumped to 205,000 albums, it's now set to hit two million units this year in the UK. I asked my teenagers, 'why, in an age of 'free' files do you buy vinyl?', and they said they liked the 'historical' sound and the physical experience.

To a grumpy old audio engineer like me, 'historical' sound means harmonic distortion in the order of a few percent, added complex noise and wow and flutter. These aberrations destroy most classical, choral and soft acoustic music, but it is an integral part of the sound of rock, dance and some pop music. The vinyl sound can be recorded with 'high fidelity' on any computer and many digital composers will even synthesise it using crackle samples and subtle pitch shifting. Fig.1 shows a budget Goldring Electra cartridge tracking an LP, it amazes me how good such a crude system can sound, but then it has had a century of incremental improvement – just like the internal combustion engine.

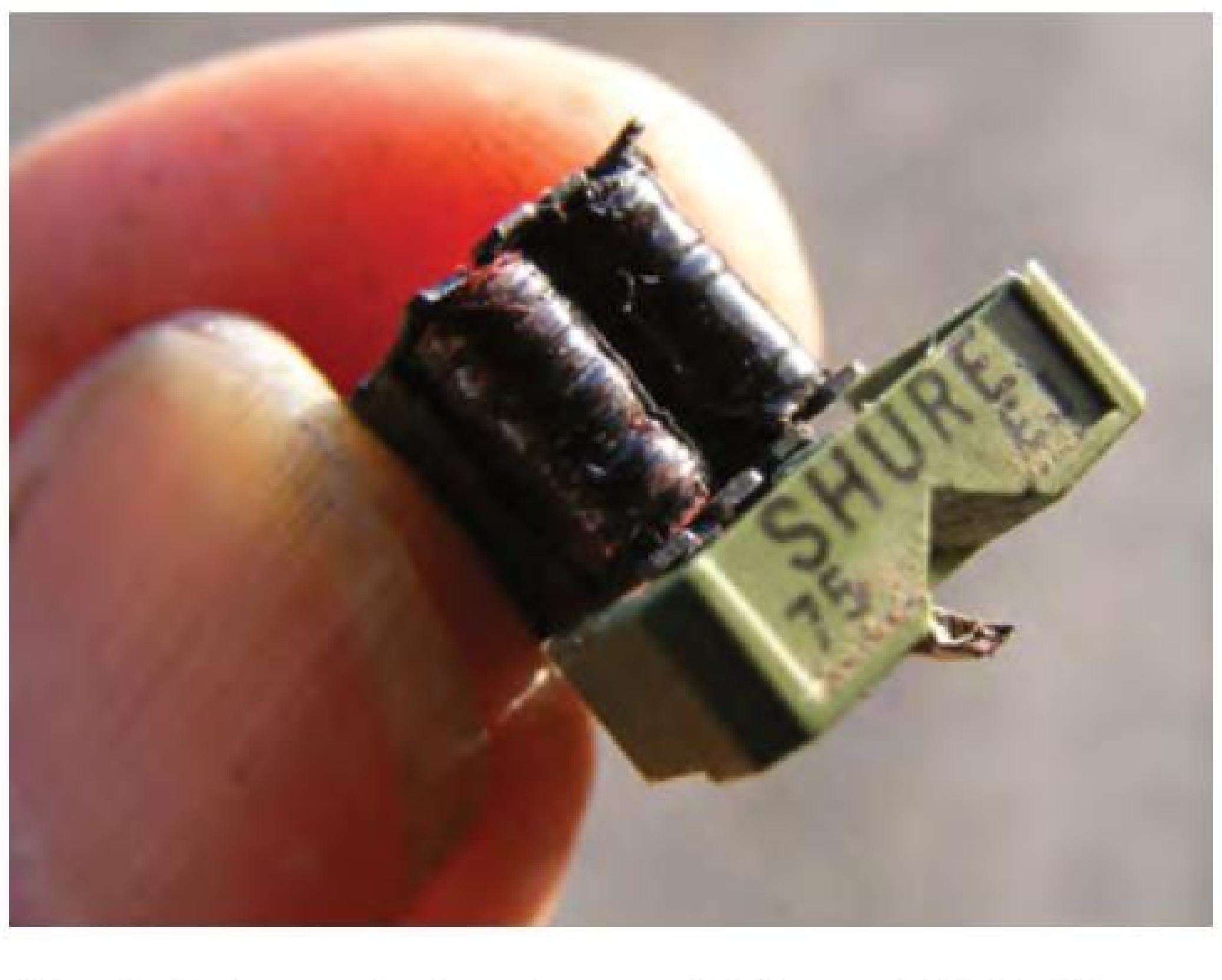


Fig.2. Internal structure of Shure's M75EJ moving magnet cartridge showing the 4 coils

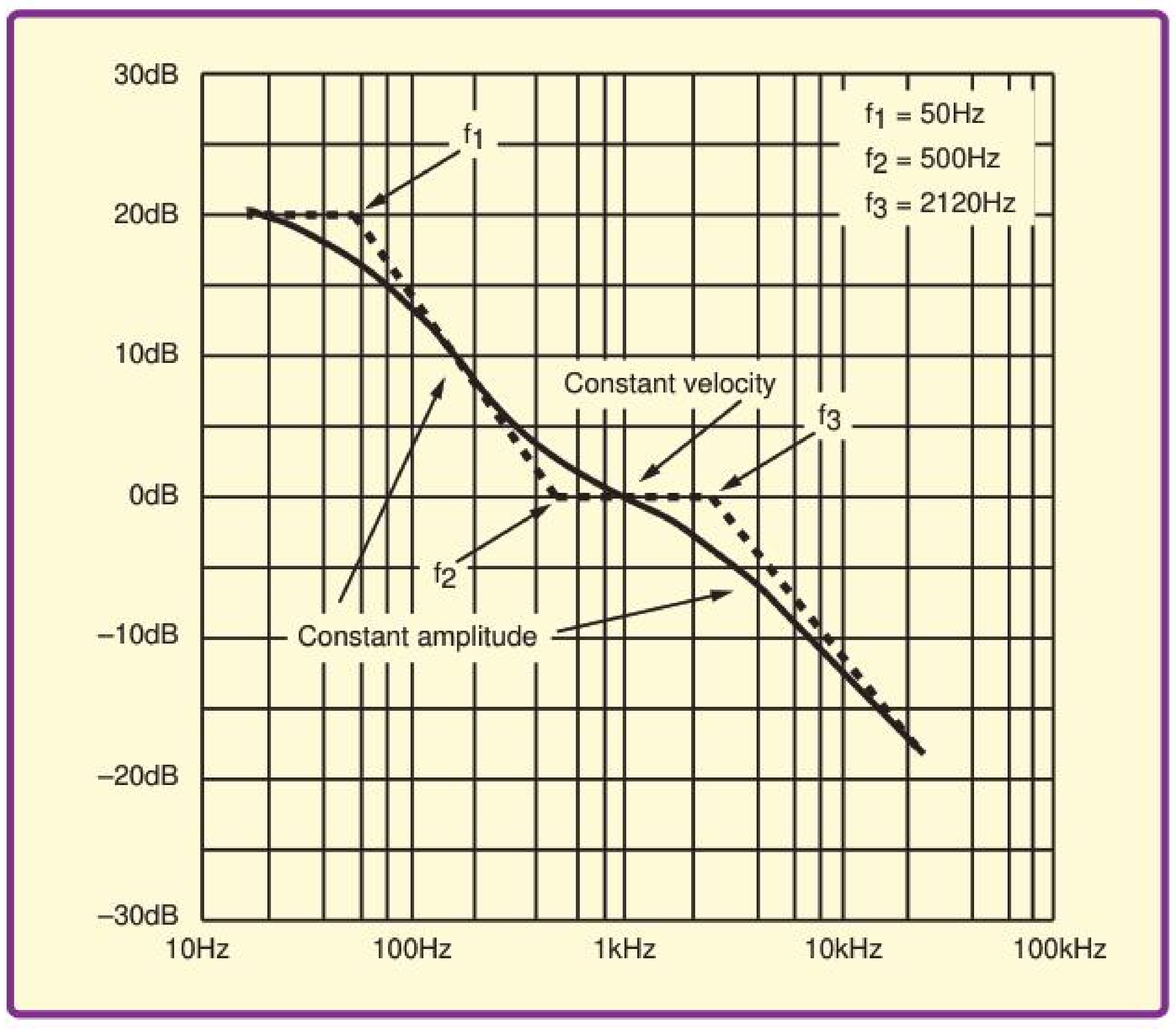


Fig.3. RIAA curve from the National Semiconductor Audio/Radio Handbook 1980 *(the best set of data books ever, yet people give them away!)*

RIAA stages

Because of the digital revolution, most amplifiers (let alone mixers and computers) no longer accept an output directly from a record deck and a special standalone pre-amplifier is needed, typically called a phono or RIAA amp. This raises the signal level from a few mV and applies the special RIAA (Record Industry Association of America) equalisation curve. Originally, record equalisation wasn't standardised and crudely consisted of treble boost when cutting the record and a complementary bass boost upon play back, to optimise the signal-to-noise ratio. Lots of variables had to be juggled to come up with the optimum curve, which wasn't finalised until the 1950s, when the audio industry very quickly implemented the RIAA standard.

Surface noise and scratches have a high frequency bias and the RIAA treble cut at 2120Hz takes care of this. Also, the bass has to be reduced on a record or the 'wiggles' on the disc will take up too much room – it's a very crude data compression algorithm! Finally, the magnetic cartridges (like all magnetic sensors) usually used for playback have an output that is proportional to the rate of change of magnetic flux, which gives an output that rises by 6dB per octave. A typical magnetic cartridge internal structure is shown in Fig.2. Thousands of turns of very fine wire are used, giving a voltage output in the order of 5mV. This comes at the cost of a high inductance value, typically 500mH, which adds another variable to the system as it resonates with any load and lead capacitance.

An equalisation curve with a straight 6dB/octave pre and de-emphasis curve across the whole 20Hz to 20kHz audio bandwidth would not work, since the resulting 60dB would be beyond the dynamic range of the mechanical system and headroom of the pre-amp. The curve finally developed by the RIAA, shown in Fig.3, was two 6dB/octave sections with a flat section around 1kHz in the centre. It keeps the grooves at constant amplitude for the top and bottom portions with a section in the middle where it is constant velocity and the amplitude decreases with frequency. This approach reduces the equalisation

Fig.4. Old Philips record player from 1974 using a ceramic cartridge

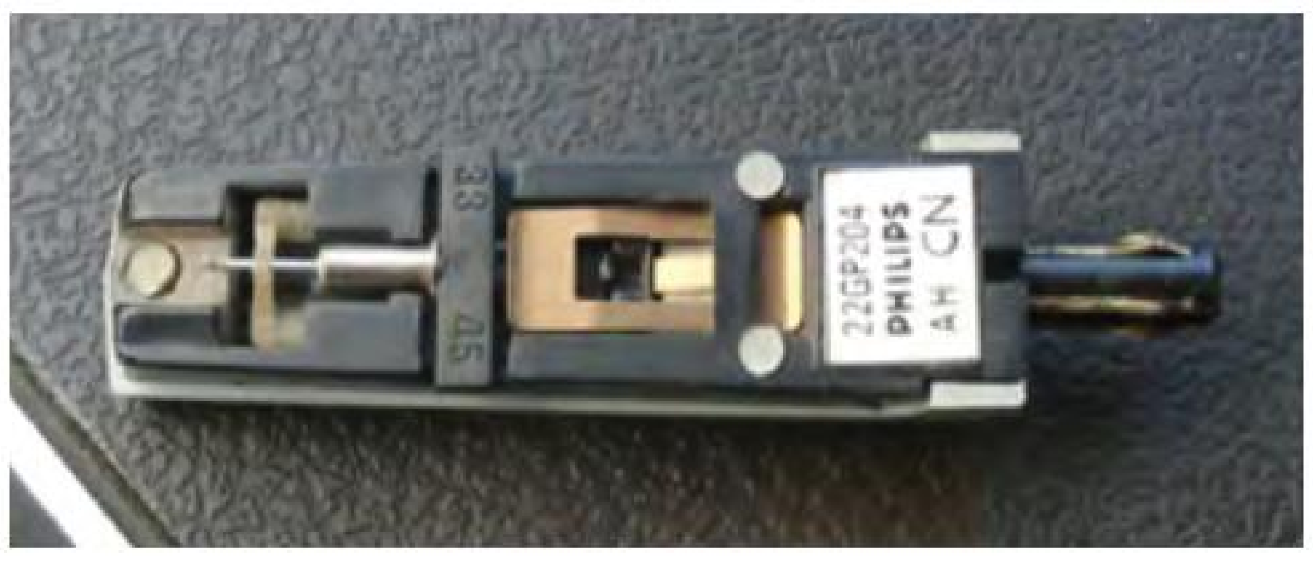


Fig.5. Ceramic cartridge: 'horrid plastic 70s tech' – sometimes useful for playing badly scratched charity shop records

required to a manageable 38.9dB. Below is a table giving the required equalisation. Note that 1kHz is taken to be the 0dB reference point. An overall gain of 30 to 45dB is usually added on top.

RIAA standard response table

These values are good for checking the curves on finished RIAA amps.

Hz	dB
20	+19.3
30	+18.6
40	+17.8
50	+17.0
60	+16.1
80	+14.5
100	+13.1
150	+10.3
200	+8.2
300	+5.5
400	+3.8
500	+2.6
630	+1.6
700	+1.2
800	+0.7
1k	0
1k25	–0.7
1k5	–1.4
2k	–2.6
2k5	–3.7
3k15	–5.0
4k	–6.6
5k	–8.2
6k	–9.6
8k	–11.9
10k	–13.7
12k	–15.3
15k	–17.2
20k	–19.6

Ceramic cartridges

Old cheap record players, such as the 'Dansette' type units illustrated in Fig.4 didn't use magnetic cartridges. Ceramic cartridges, which operated on the piezoelectric effect, were employed. Fig.5 shows a traditional stereo ceramic cartridge which contains two bi-morph barium-titanate elements. Ceramic cartridges give around 500mV into a high impedance, and in conjunction with their high intrinsic capacitance, an approximate facsimile of RIAA equalisation results. The cheapest players used a single valve or a greater-than-1MΩ-input impedance power-amp circuit (Fig.6).

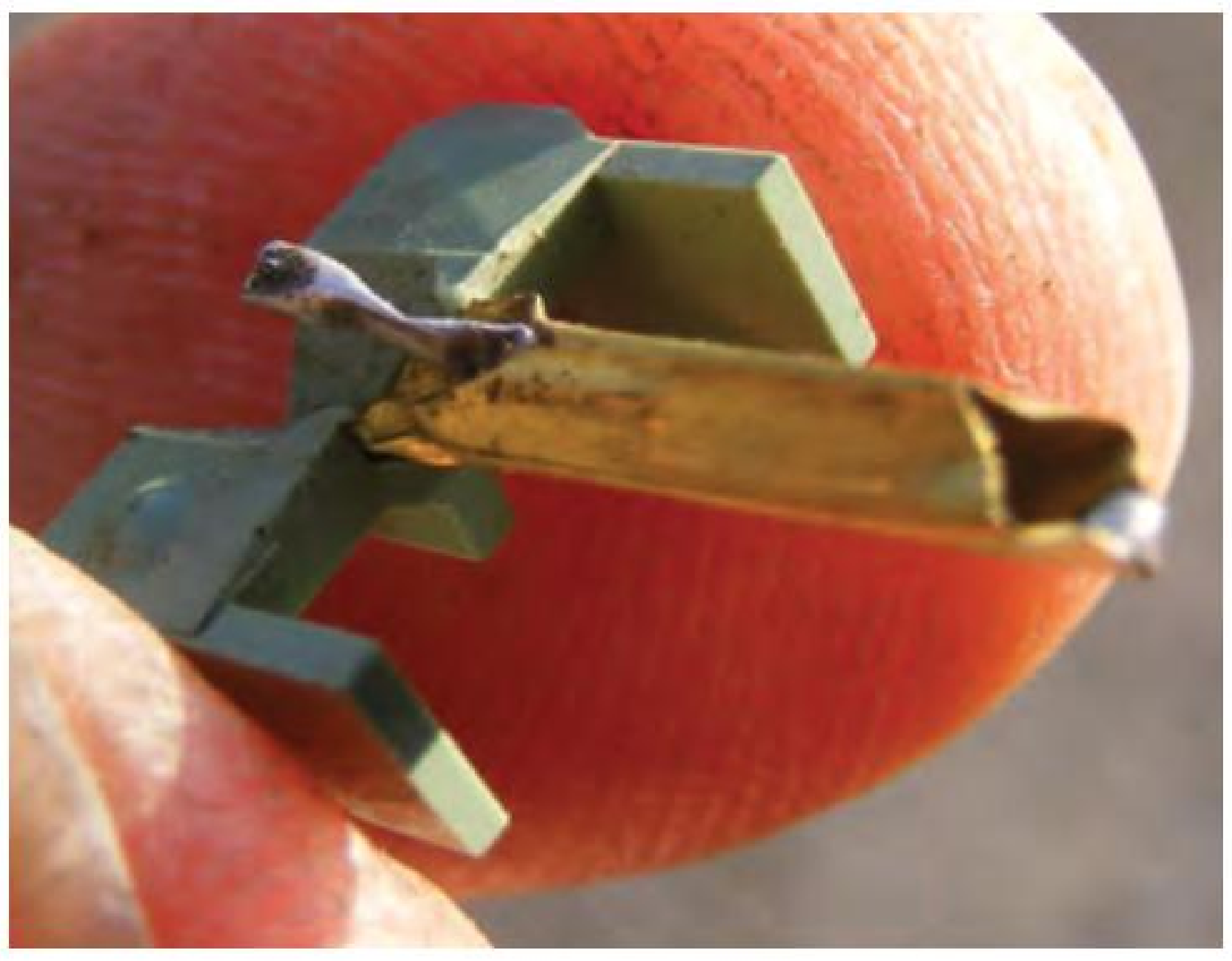


Fig.7. Moving magnet stylus assembly from a Shure M75EJ. The magnet is inside the brass casing. On this example the cantilever has suffered drunken-musician abuse!

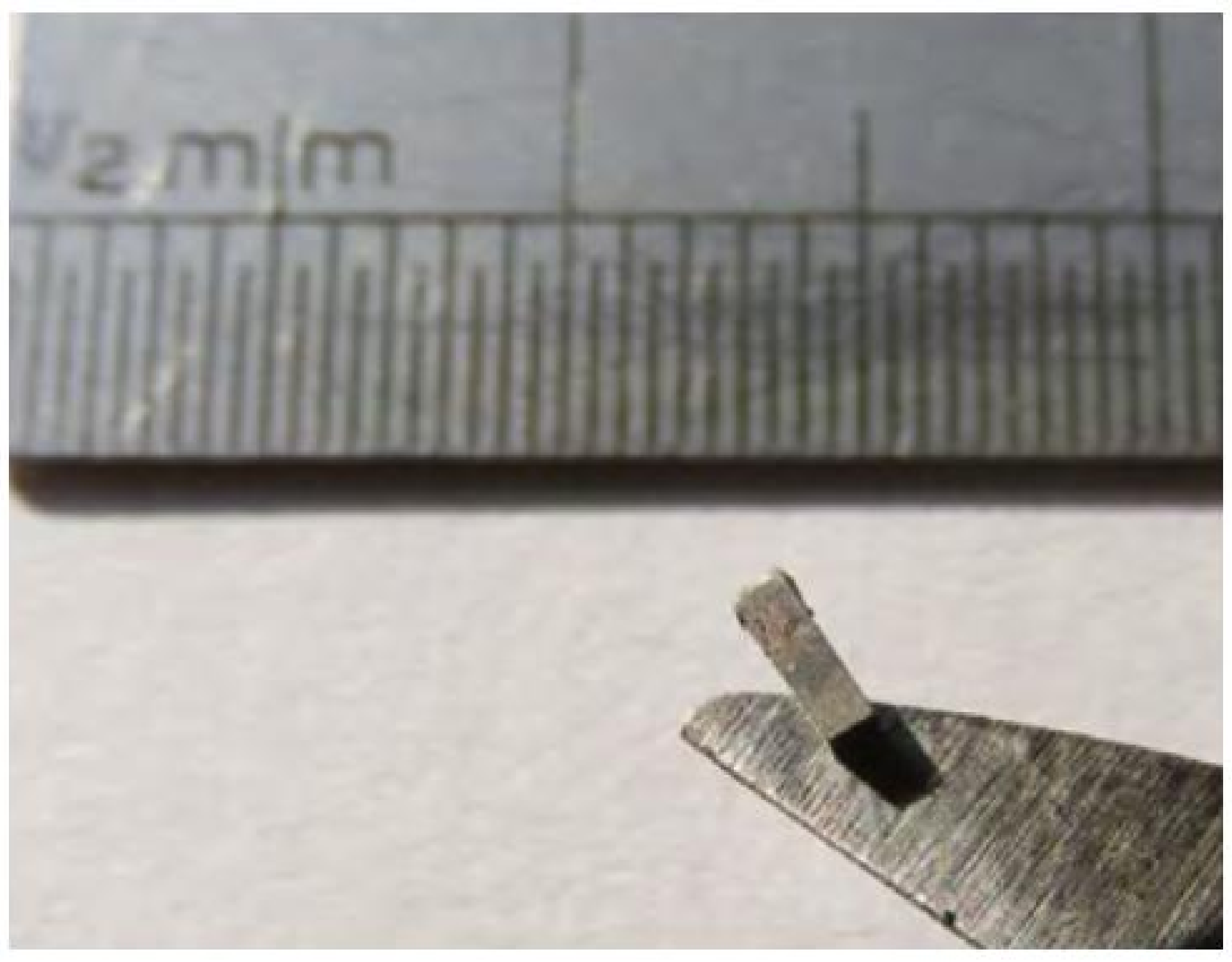


Fig.8. The very small magnet used at the end of a moving-magnet cartridge cantilever. This adds significant mass to the cartridge's moving assembly

Moving-magnet and moving-coil cartridges

Ceramic cartridges and their associated styli are no longer made. but do manage to attract silly 'antique' prices. Magnetic cartridges are now dominant and come in two forms, *moving-magnet* and *moving-coil*. The moving-magnet type is the most common because it is simple and efficient (and cheaper). A small magnet is attached to the end of the cantilever, a fragile aluminium tube onto which is fitted the diamond. Fig.7 shows the stylus assembly (the magnet is inside the brass casing), and Fig.8 shows a tiny magnet from a moving-magnet cartridge. Sometimes the diamond is glued on (it has a tendency to fall off, as with the Orfoton FF15) or pushed into a hole as in the more robust Shure M75EJ and Stanton 500A designs.

The moving magnet induces a varying magnetic field in the pole-pieces on which the coils are mounted. There is a slight non-linearity due to magnetic hysteresis with this system. This can be eliminated with moving-coil designs where the stylus assembly directly moves the coils in a magnetic field, which can now be produced by a much larger magnet, since it doesn't move. Most Hi-Fi buffs prefer moving-coil cartridges because of their lower magnetic distortion and lower inductance, which give a supposedly more transparent sound. Professional users tend to prefer moving-magnet designs. The slightly higher performance of moving-coils comes at the cost of an output voltage that's 10-times lower, because the coils have to be much smaller to minimise the moving mass. The mechanical structure is also less compliant and has more resonances due to the lead-out wires from the coils that have to bend with the stylus motion. Consequently, more mechanical energy is transmitted into the tone arm, which means this has to be dealt with by expensive mechanical engineering to avoid colouration. To cap it all, the stylus is often permanently attached and not user replaceable. This is often used by the maker as an excuse to sell you a new cartridge upgrade for a few hundred pounds.

My exposure to moving-coil cartridges has been a Hi-Fi experience akin to protection insurance from banks. If you must use one, an additional input stage is required in front of the standard moving-magnet pre-amplifier to boost the voltage by 10-times and match it into a very low source impedance, typically 3 to 25Ω. A transformer is often used for this, as shown in Fig.9. Alternatively, a special transistor with a very low base spreading resistance (R_b) such as the 2N4403, 2SA1085 or the elusive 2SB737 is required. Maybe a germanium device would work well here?! (See the last three *Audio Out* pieces on Germanium technology.)

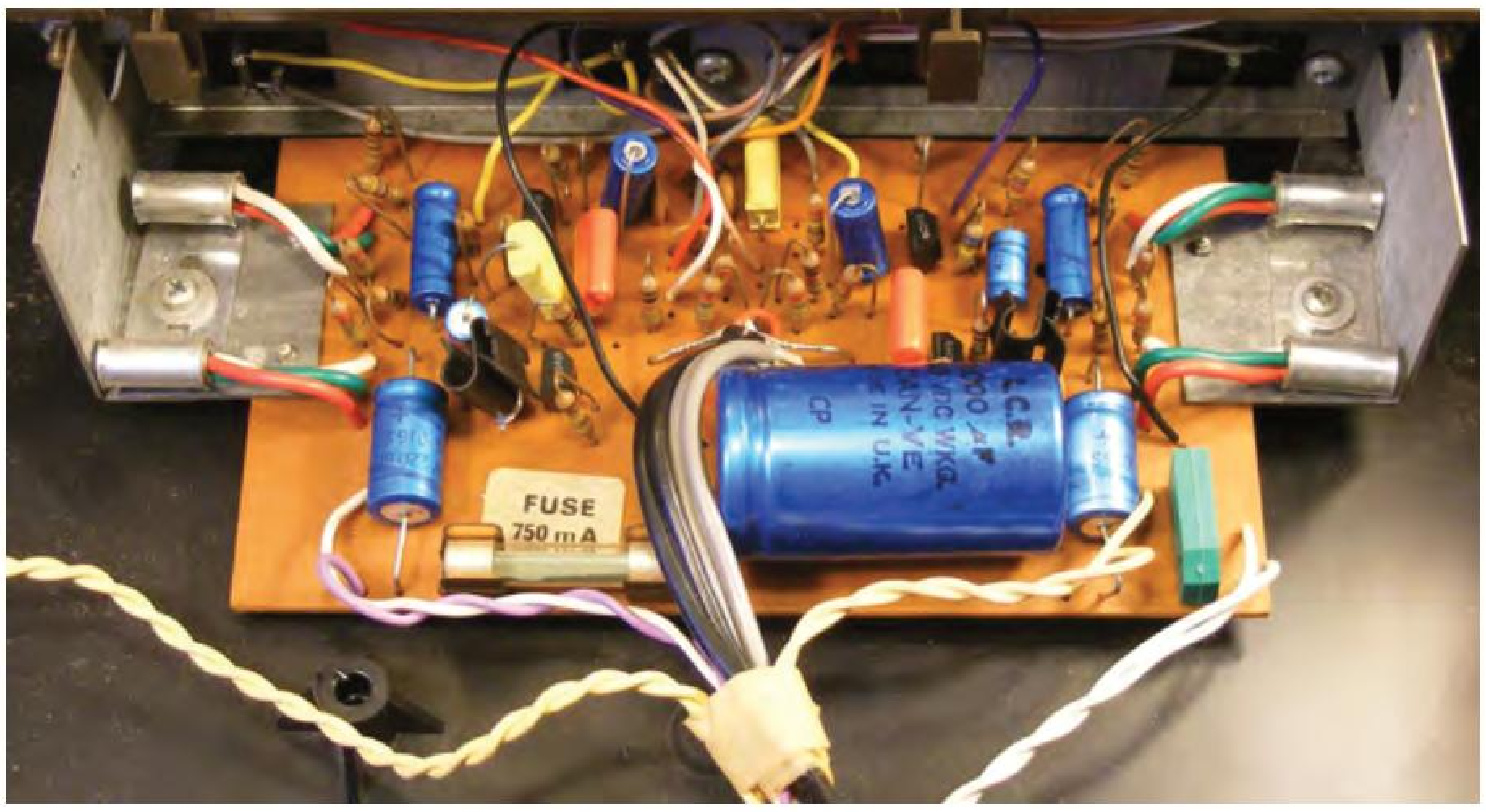


Fig.6. Philips record player amplifier; note the germanium output transistors

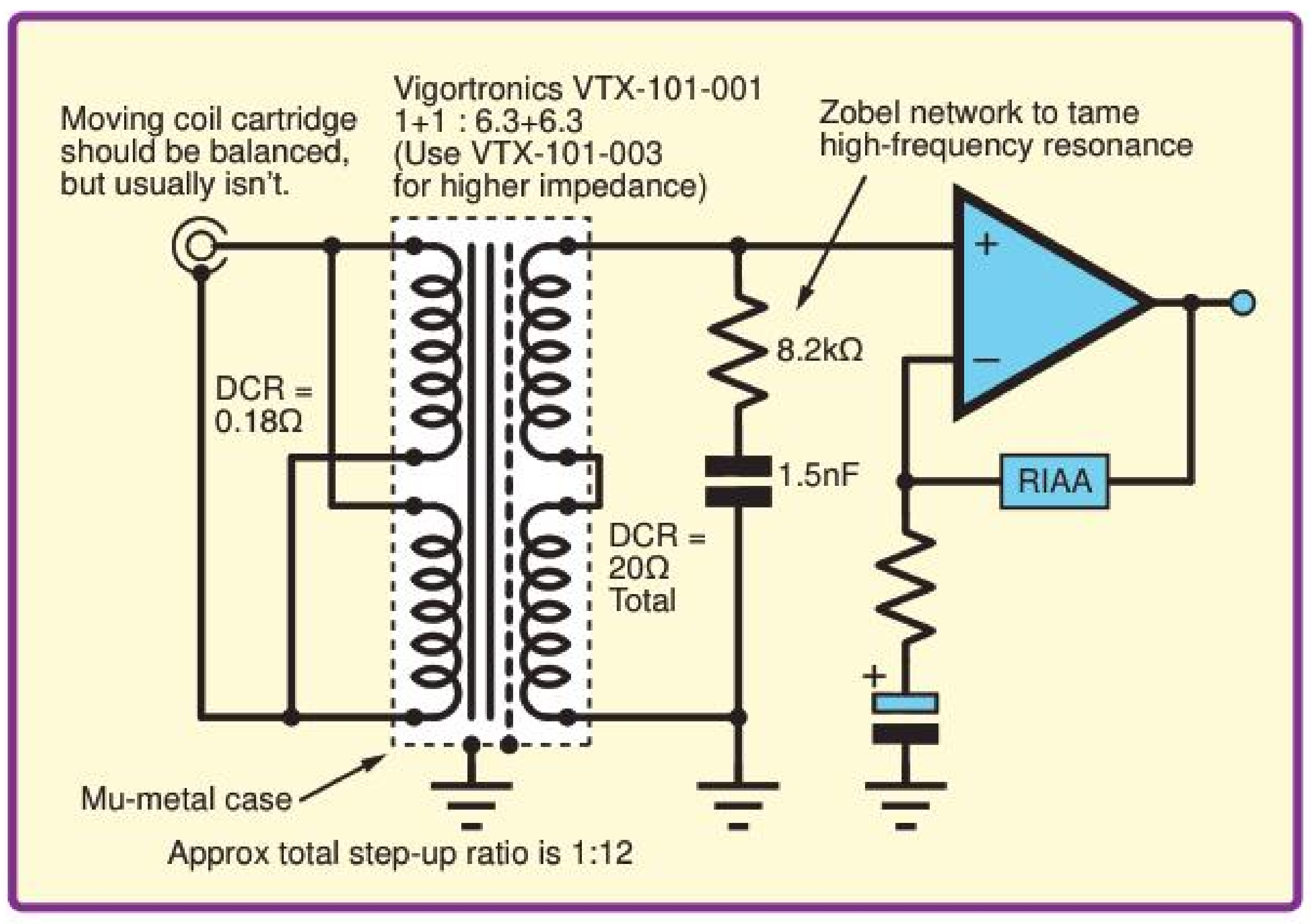

Moving coil cartridge should be balanced, but usually isn't.
Vigortronics VTX-101-001
1+1 : 6.3+6.3
(Use VTX-101-003 for higher impedance)
Zobel network to tame high-frequency resonance
DCR = 0.18Ω
8.2kΩ
+
–
1.5nF
RIAA
DCR = 20Ω Total
+
Mu-metal case
Approx total step-up ratio is 1:12

Fig.9. A transformer is often used to convert a moving-magnet input to a moving-coil input. There are two Vigortronic types that are suitable. I usually use the higher impedance one. (Note: 'DCR' = DC resistance)

Max's Cool Beans

By Max The Magnificent

No such thing as too many LEDs

Call me old-fashioned if you will, but I personally don't think you can have too many light-emitting diodes (LEDs) in your hobby projects or embedded systems. Furthermore, given a choice, I prefer to use tri-coloured devices, each of which contains a red, green, and blue (RGB) LED, the light from which can be subtly mixed to give millions of different colours.

In the not-so-distant past, using more than one or two tri-coloured LEDs could be something of a pain because you quickly ran out of microcontroller (MCU) pins and resources. When I first conceived my *Inamorata Prognostication Engine* project about 10 years ago, for example, my prototypes quickly grew to be unduly complex and unwieldy (check out this breadboard-based test platform to see what I'm talking about: **http://bit.ly/1AcJEEf**). More recently, some really amazing devices called WS2812B LEDs (each presented in a 5mm × 5mm square package that's only about 2mm thick) have come onto the market. Using these little rainbow scamps, you can control hundreds of tri-coloured LEDs using a single microcontroller pin, if you so desire.

Full-spectrum lighting examples

Just to give you an idea of the effects you can achieve with these devices, check out this video of my *Vetinari Clock* prototype (**http://bit.ly/195JKWR**). In this case, one MCU pin is being used to control a 16-element ring of tri-coloured LEDs mounted under the vacuum tube. Another example is my *Bodacious Acoustic Diagnostic Astoundingly Superior Spectromatic* (*BADASS*) display, which employs 16 strips, each containing 16 elements, forming a 16 × 16 = 256 tri-coloured display (**http://bit.ly/1bATrxK**).

LED fundamentals

Now, just to make sure we're all tap-dancing to the same drum beat, let's remind ourselves of a few fundamental factoids before we leap into the fray with gusto and abandon. A semiconductor diode is a device that conducts electricity in only one direction, as illustrated in Fig.1a and 1b.

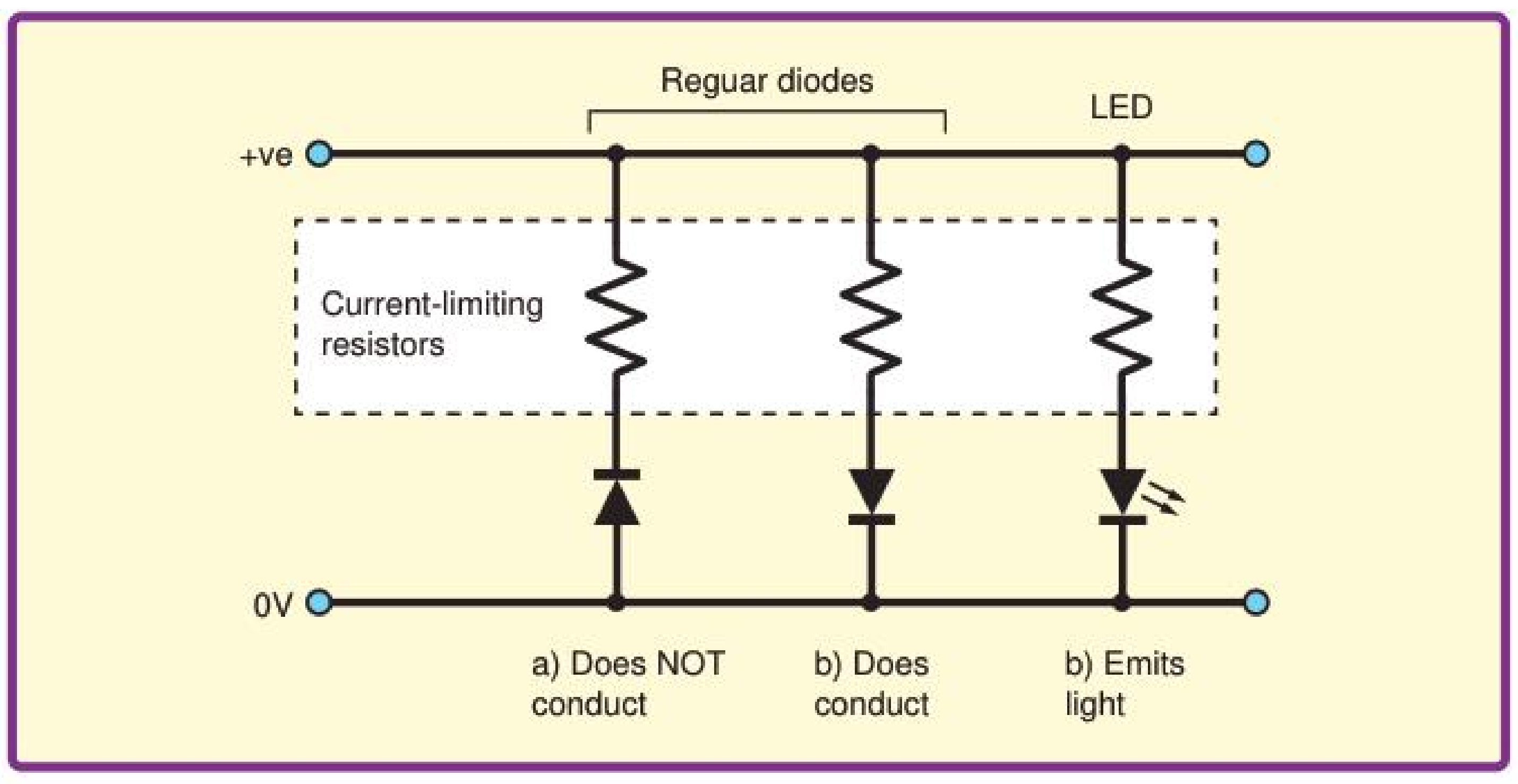
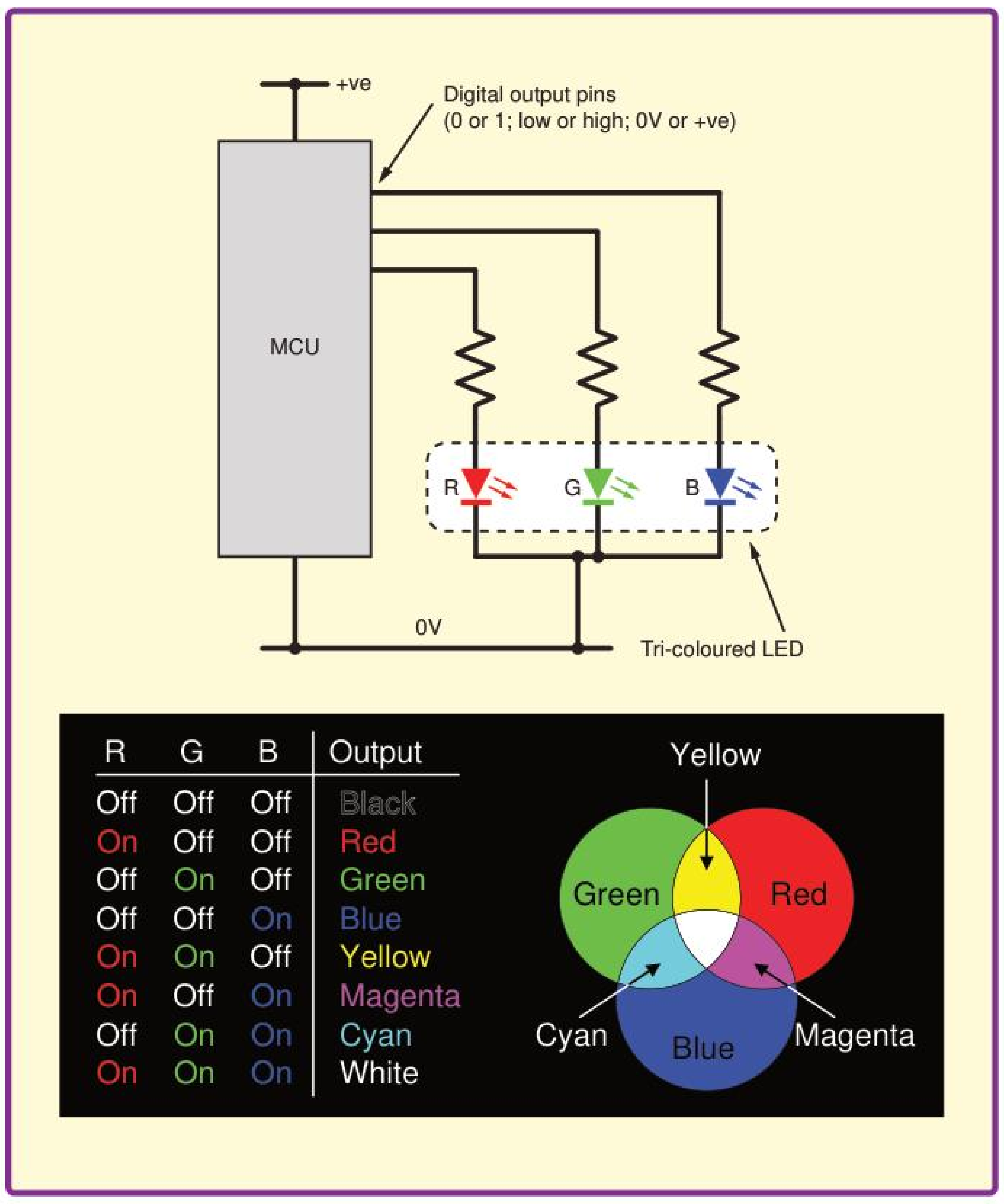


Fig.1. Diodes conduct in only one direction



R	G	B	Output
Off	Off	Off	Black
On	Off	Off	Red
Off	On	Off	Green
Off	Off	On	Blue
On	On	Off	Yellow
On	Off	On	Magenta
Off	On	On	Cyan
On	On	On	White

Fig.2. Using an MCU to control a tri-coloured common-cathode LED

An LED is a diode constructed out of special semiconducting materials that emit light when the device is conducting. The fact that this is an LED is indicated by the two arrows associated with the symbol. The cathode (negative terminal) is connected to the more negative power rail (0V in this example), while the anode (positive terminal) is associated with the more positive power rail.

Some LEDs come equipped with current-limiting resistors inside the package. On the one hand, this makes things simpler because you have fewer components to worry about, but it does mean you have to select LEDs that are matched to the voltage source you are using. If you have to use an external current-limiting resistor as illustrated in Fig.1, then it's easy to calculate the required value. The LED's data sheet will specify something called the 'forward voltage' or 'voltage drop' V_f; let's assume that this is 2V for our example LED. The data sheet will also specify a 'forward current' I_f; let's assume this is 20mA for our LED. If we further assume that

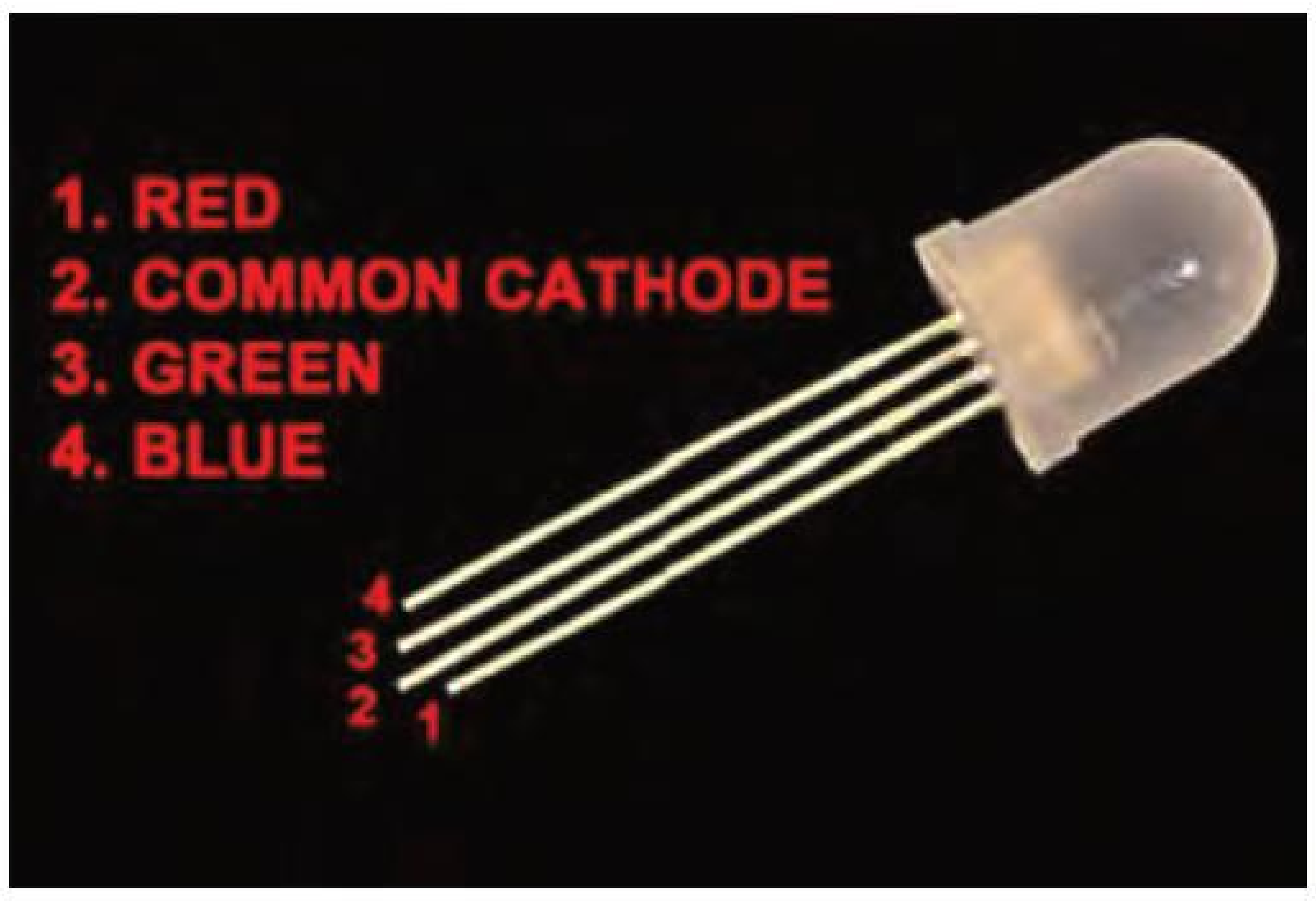


Fig.3. Tri-coloured LED connections

we're working with a 5V supply, then using Ohm's law ($V = I \times R$), we can calculate our current-limiting resistor to be:

$$R = (5V - V_f) / I_f = (5V - 2V) / 0.020A = 150\Omega.$$

Also note that it doesn't really matter whether we place the current-limiting resistor between the LED's anode terminal and the +ve rail, or between its cathode terminal and the 0V rail, just so long as we include it in series with the LED in the circuit.

Tri-coloured LEDs

Now let's consider a tri-coloured device. As we previously discussed, this involves having red, green, and blue LEDs in a single package. A traditional package is illustrated in Fig.2 and Fig.3. Once again, some of these devices come equipped with their current-limiting resistors (one per LED) inside the package. Others, like the one shown in Fig.2 and Fig.3, require external resistors. In this case, you need to check the data sheet for each channel (colour), because the LEDs may have different V_f and I_f values.

For the purpose of these discussions we're assuming a common-cathode device (common-anode versions are also available). In this case, the common cathode would be connected to 0V, and connecting the other leads to the +ve power source would turn the corresponding channels on. A very common technique is to use a microprocessor to control the device. Let's assume that we're using an Arduino, and that its digital pins 6, 7 and 8 are being used to drive the red, green, and blue (RGB) channels, respectively. In this case, the statement `digitalWrite(6,HIGH);` will turn the red channel fully on, while `digitalWrite(6,LOW);` will turn it off again.

If we limit ourselves to simply turning each channel on or off, then we end up with 2^3 = 8 different colour combinations (assuming the all off = black combination is a colour). Alternatively, if we vary the brightness of the channels, we can generate millions of colours. We will consider some of the techniques we can use to do this in my next column. Until then, have a good one!

Toot toot!

As an aside, my wife (Gina The Gorgeous) is an estate agent. Last weekend she met a couple who were looking at houses. It turns out that the husband builds model train dioramas as a hobby. When Gina told him I was ~~the world's leading~~ an electronics engineer, he said that he needed some help with his trains, so she gave him my email address (I wish she'd stop doing that!). Anyway, he emailed me to say that he would like to be able to light up his model houses, and to vary the light colours and sequence them and suchlike, but he has no clue how to do it. I replied that I had a solution that would have him performing a happy dance, and he's going to visit my office one lunchtime this week for me to explain how he can use WS2812B LEDs to satisfy all of his luminary desires…

…and did you know that you say 'a LED' if you say 'LED' as one word to rhyme with 'bed'; and you say 'an LED' if you spell out 'L-E-D' as separate letters.

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CIRCUIT SURGERY

REGULAR CLINIC

BY IAN BELL

LTSpice modulator and other special functions

REGULAR readers know we often use LTSpice circuit simulations to illustrate *Circuit Surgery* articles. LTSpice is also popular with *EPE Chat Zones* contributors, who quite often post simulation files in discussions. This month's topic is specifically about the use of LTSpice: frequent contributor ***atferrari*** posted the following question.

> *LTSpice simulation – I could not find a way to implement this:*
>
> *a) Testing a circuit fed with a fixed-amplitude sinusoidal voltage source with varying frequency along a certain period. Say, in two seconds from 6kHz to 450Hz with 0.5V amplitude.*
>
> *b) I would also like to test the same circuit in the same period at a fixed frequency with a varying amplitude.*
>
> *c) Then, mixing both options.*
>
> *Is such a thing possible? I fear I am out of luck here. Please note that I am not trying to do a .tran simulation; my test is in one pass along time and stepping a parameter is not what I need either (well, the way I know to use it, at least...). Suggestions appreciated.*

A solution was posted by another frequent contributor – ***741*** – who suggested use of the 'Modulator special function device'. We will look at this LTSpice modulator device, describe how to use it and discuss some more general aspects of the set of special function devices in LTSpice.

Special functions in LTSpice

The Modulator is one of Linear Technology's proprietary special function behavioural models. There are a number of these, with various levels of documentation. The modulator is described in the LTSpice help file, but other special functions are more obscure and some have disappeared, after having been 'available' in earlier versions.

The undocumented special functions of course stir interest among some sections of the user community (some of whom try to document them). Linear Technology states in the help file: 'Most of these and their behaviour are undocumented as they frequently change with each new set of models available for LTspice'. Although some functions appear to be stable, this probably has some truth in that Linear Technology may not want the burden of having to fully document and maintain them as primary features of LTSpice.

The modulator is an idealised voltage-controlled sinewave oscillator. Two input voltages independently control the output frequency and amplitude, allowing the modulator to perform frequency modulation (FM), amplitude modulation (AM) or a combination of the two. We will describe its behaviour in more detail later.

The modulator, and some other special functions, are available via the usual component command button and are found, unsurprisingly, in the 'Special Functions' folder. Most of the models in this folder are for Linear Technology devices that do not fit into the other category folders, such as op amps, comparators and power products (regulators). There is also a set of Special Functions in the Digital folder, including logic gates and flip-flops.

The modulator is not just a symbol, but as the description 'proprietary special function behavioural models' implies, it is a built-in model, and so will do something in a simulation without you having to supply/reference the model code yourself. This is not true for all symbols in the component library – for example, there is a symbol for an SCR/thyristor; but to use it you have to write (or at least search online for) a suitable model and include the model reference on the schematic.

The special function described in the LTSpice help file are shown in Table 1. If you check the list in the 'Select Component Symbol' dialog you will find a few more. Some of these (BUF1, DIFFSCHMITT, DIFFSCHMTBUF, DIFFSCHMTINV, and MODULATE2) are just variations on the above models, but there are also a few different undocumented functions, namely SRFLOP (SR flip flop), PHIDET (phase detector), COUNTER (divide by N counter/frequency divider), CAPMETER (vector impedance meter) and SAMPLE (sample and hold).

We will look at the modulator special function in more detail and also make some general observations and comments which apply to all the special function behavioural models. The modulator and modulator2 symbols are shown in Fig.1. Note that they have names, starting with 'A' – this is true for all special function behavioural models (just as resistor names start with 'R' and capacitors with 'C').

Looking at a schematic, it is not obvious that all of these special functions have eight connections

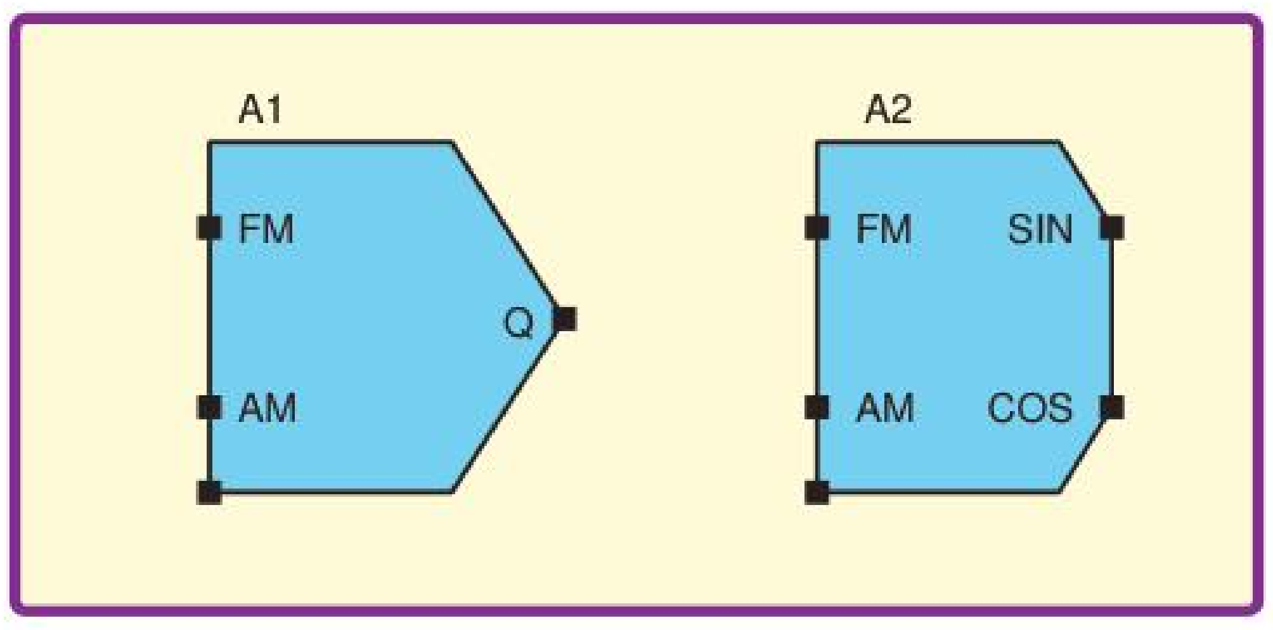


Fig.1. LTSpice modulator symbol

Table 1: Special functions listed in LTSpice help

INV	inverter or NOT gate
BUF	logic buffer with complementary outputs
AND	AND and NAND gates
OR	OR and NOR gates
XOR	XOR and XNOR gates
SCHMITT	Schmitt-trigger buffer with complementary outputs
SCHMTBUF	Non inverting Schmitt-trigger buffer
SCHMTINV	Inverting Schmitt-trigger buffer
DFLOP	D-type flip-flop
VARISTOR	Voltage-controlled varistor (breakdown impedance)
MODULATE	Voltage-controlled oscillator

– some of the connections may be unused (for any given model) and hence not shown on the symbol. We also see an odd-looking unnamed connection, called the device common, at the bottom left-hand corner of the symbol. These appear on all the special function symbols and we will explain them shortly, but first we need to define how circuits are described to the simulator.

Nets and netlists

The LTSpice simulator does not work by reading directly from the schematic; the schematic capture part of the software generates a text description of the circuit, called a netlist, which provides the input to the simulator. You can look at the netlist using the 'SPICE Netlist' command from the View menu.

The term 'net' is more or less synonymous with wire (at least an electrically ideal wire) and a 'netlist' file is basically a wiring list, although it may also contain other information such as simulator options and simulation instructions. Nets are named in the order they are drawn; eg, as N001, N002…, unless they are explicitly given a different name by the user via the Label Net command button or right click menu.

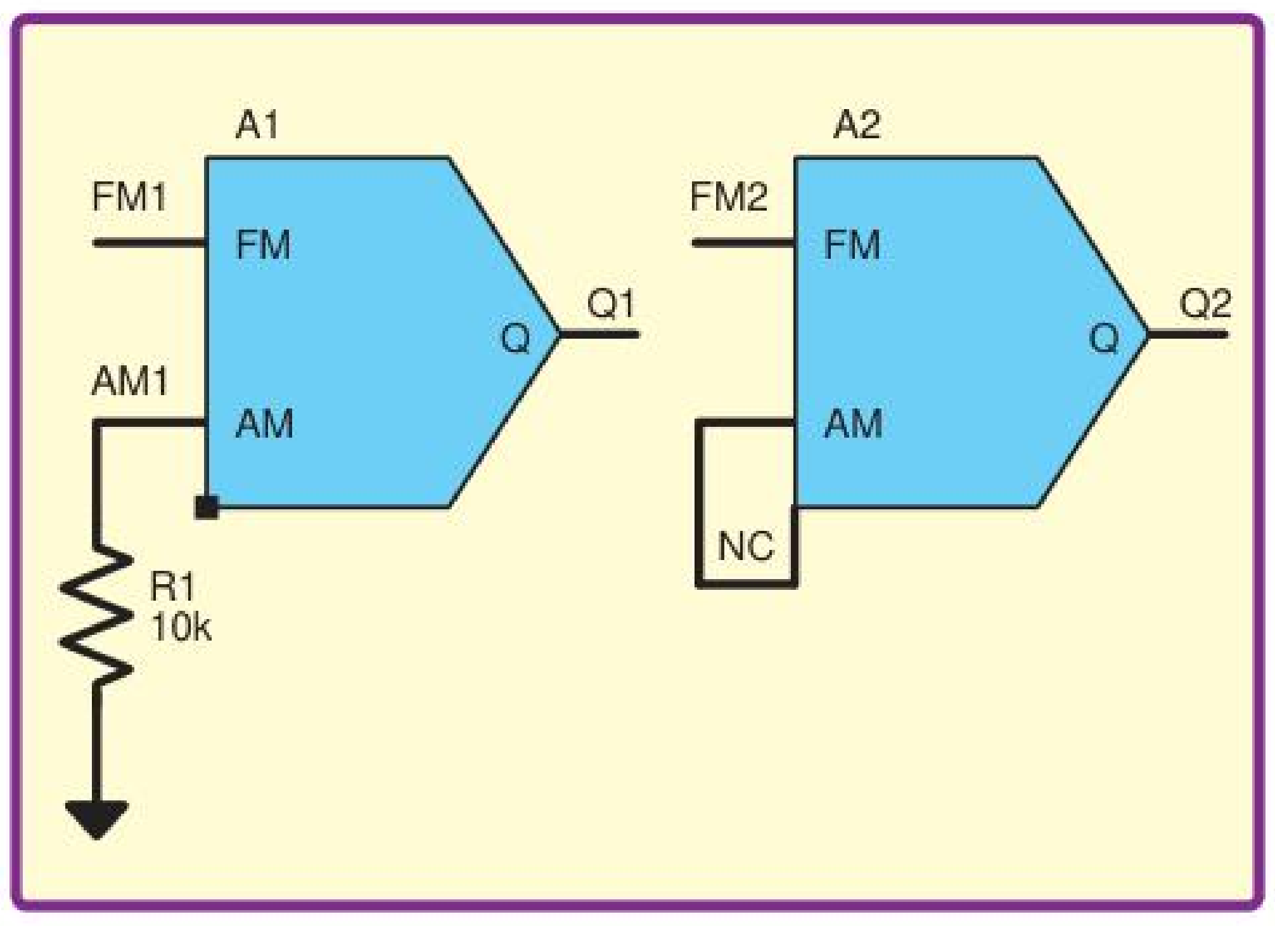


Fig.2. LTSpice schematic to illustrate netlisting and special functions

Ground zero

The name '0' (zero) is a special case; it represents ground – the reference point from which all circuit voltages in the simulation are measured. There must be a ground net for a SPICE simulation to run (correctly). LTSpice will issue an error if there is no ground in the circuit.

The schematic shown in Fig.2 results in the following netlist. This schematic does not represent a usable or meaningful circuit, it is just to illustrate a couple of points about netlists and special functions.

```
* C:\Program Files (x86)\LTC\LTspiceIV\Draft1.asc
A1 FM1 AM1 0 0 0 0 Q1 0 MODULATOR
A2 FM2 NC NC NC NC NC Q2 NC MODULATOR
R1 AM1 0 10k
.backanno
.end
```

Netlist syntax

The syntax of the netlist is not too difficult to decode. Each component in the schematic gets its own line. The first item on the line is the component name (in this case, A1, A2 and R1). This is followed by the list of wires to which the component is connected. These are in a specific order – although it does not really matter for the resistor, but the modulator's various connections have different functions, so the order is important. The netlist also contains commands to the simulator, which start with a full stop, and comments, which start with an asterisk.

In the netlist above we can see (as expected) that the resistor has two connections (to nets AM1 and 0). We also see that the two modulators have eight connections, as noted above. However, the modulator symbol only has three normal connections (AM, FM and Q), which, for modulator A1, are connected to wires FM1, AM1 and Q1. The netlist is consistent with this in that all these wires are listed in association with the A1 component.

So why does it have eight connections? This is just the way the special functions are set up – all special functions have eight connections. It means that (in the case of the modulator) some connections are unused. The simulator knows this and deals with it when processing the netlist to build the simulation model for the circuit. This approach makes more sense when you consider the logic gates, such as AND and OR. Logic gates can have different numbers of inputs (2, 3 and 4 input gates are particularly common). The LTSpice special function gates may have from 2 to 5 inputs and they have both true and false outputs, so one function is required, for example, for both AND and NAND. One special function symbol covers eight possible logic gates (or 12 if you include versions with both true and inverted outputs).

The eighth connection of special function components on the netlist is the device common, which we mentioned earlier, and which has special properties. Looking at the netlist above, we see that if the common connection ('bottom left-hand corner' connection on the modulator symbol) is not connected in the schematic, as for A1, it, and all the unused connections, are connected to node 0 (ground).

If unused connections are wired to the special common connection, as for A2, then they are all connected to that net. This applies to both unused connections in the model itself (the modulator has no I/O for the third to sixth connections) and to unused model connections (for example the AM input of A2 is designated unconnected by wiring it to the common connection). This allows LTSpice to identify unconnected model I/O and take appropriate action (for example to simplify the simulation model).

In the case of logic gates, there may be significant difference between not wiring unused inputs at all (so they and the common are on net 0) and explicitly connecting them to the gate's common. For example, in the former case, net zero is designated the 'disconnect' net so explicitly grounded (0V) inputs will also behave as disconnects rather than logic low inputs. For logic gates, unused inputs must be wired to the common (as we have done with AM in Fig.2). For the modulator this is not so important.

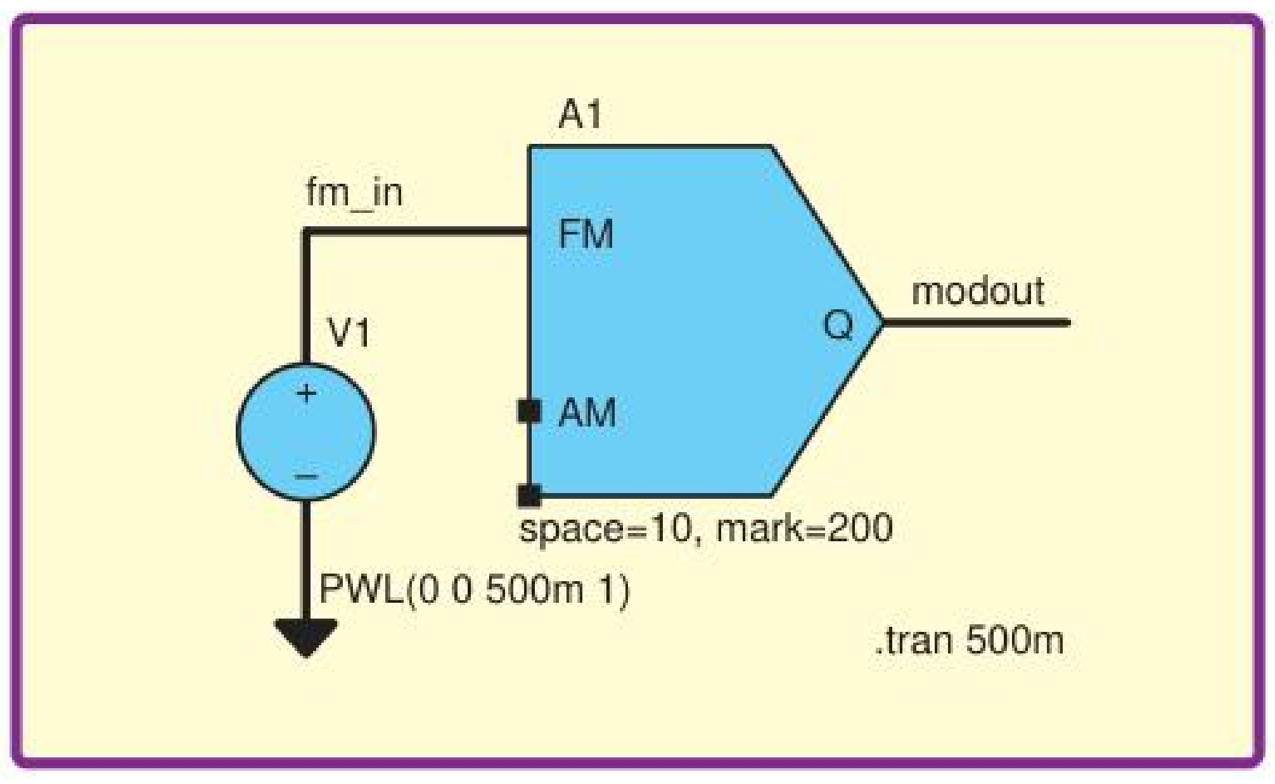
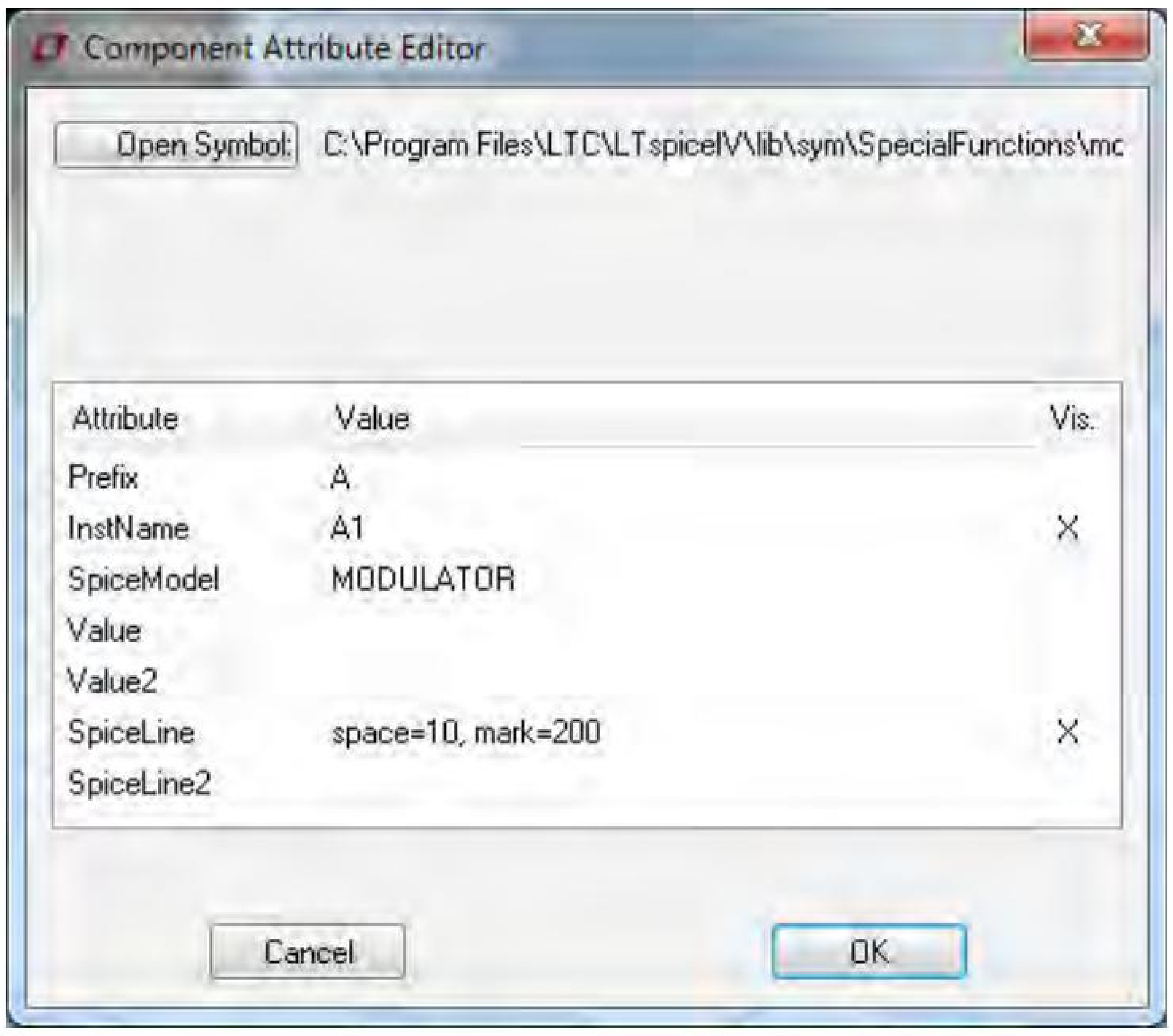


Fig.3. LTSpice circuit to demonstrate FM action of modulator

Simulating frequency modulation

The circuit in Fig.3 shows the modulator wired to demonstrate the frequency modulation (FM) function. In order for the modulator to work it is necessary to define the value of a couple of parameters (space and mark). Initially these will not be set and will not appear on the schematic. As with basic components, where, for example, you can set the resistance (parameter) of a resistor by entering data in the named box, we proceed by right-clicking on the symbol. However, unlike a resistor, we do not get a device-specific dialogue; instead we are presented with the general purpose Component Attribute Editor, as shown in Fig.4.

In order to use the Component Attribute Editor to define parameter values we need to know the parameters names. This is not a problem with the modulator because these are documented in the help file. However, for anyone wishing to explore undocumented special functions this may be more problematical. The parameter values are entered into the 'SpiceLine' sections of the Component Attribute Editor. You can put a number of parameters in each line, separated by commas, using the general format: `name=value`, where `name` is the parameter's name (as given in the help file) and `value` is the value expressed



C:\Program Files\LTC\LTspiceIV\lib\sym\SpecialFunctions\mc

Attribute	Value	Vis.
Prefix	A	
InstName	A1	X
SpiceModel	MODULATOR	
Value		
Value2		
SpiceLine	space=10, mark=200	X
SpiceLine2		

Fig.4. The Component Attribute Editor with modulator parameters added

in the usual Spice format. If you would like the list of parameter settings (the SpiceLine) to be displayed on the schematic you need to put an 'x' in the 'Vis' column of the Component Attribute Editor for the SpiceLine concerned.

The two parameters for the Modulator are 'Space' and 'Mark'. These set the lower and upper frequencies produced by a 0V and 1V input respectively on FM. The output frequency scales linearly between the Space and Mark frequencies for FM input voltages between 0V and 1V. The circuit in Fig.3 drives the modulator's FM input from a basic voltage source with a piecewise-linear configuration, which ramps the FM voltage from 0V to 1V over 500ms. For the circuit in Fig.3, use of Space and Mark values of 10 and 200 means that the modulator output frequency steadily increases from 10Hz to 200Hz over a 500ms time period. The AM input is disconnected, which causes the modulator to default to a peak output voltage of 1V. The results of simulating the circuit in Fig.3 are shown in Fig.5.

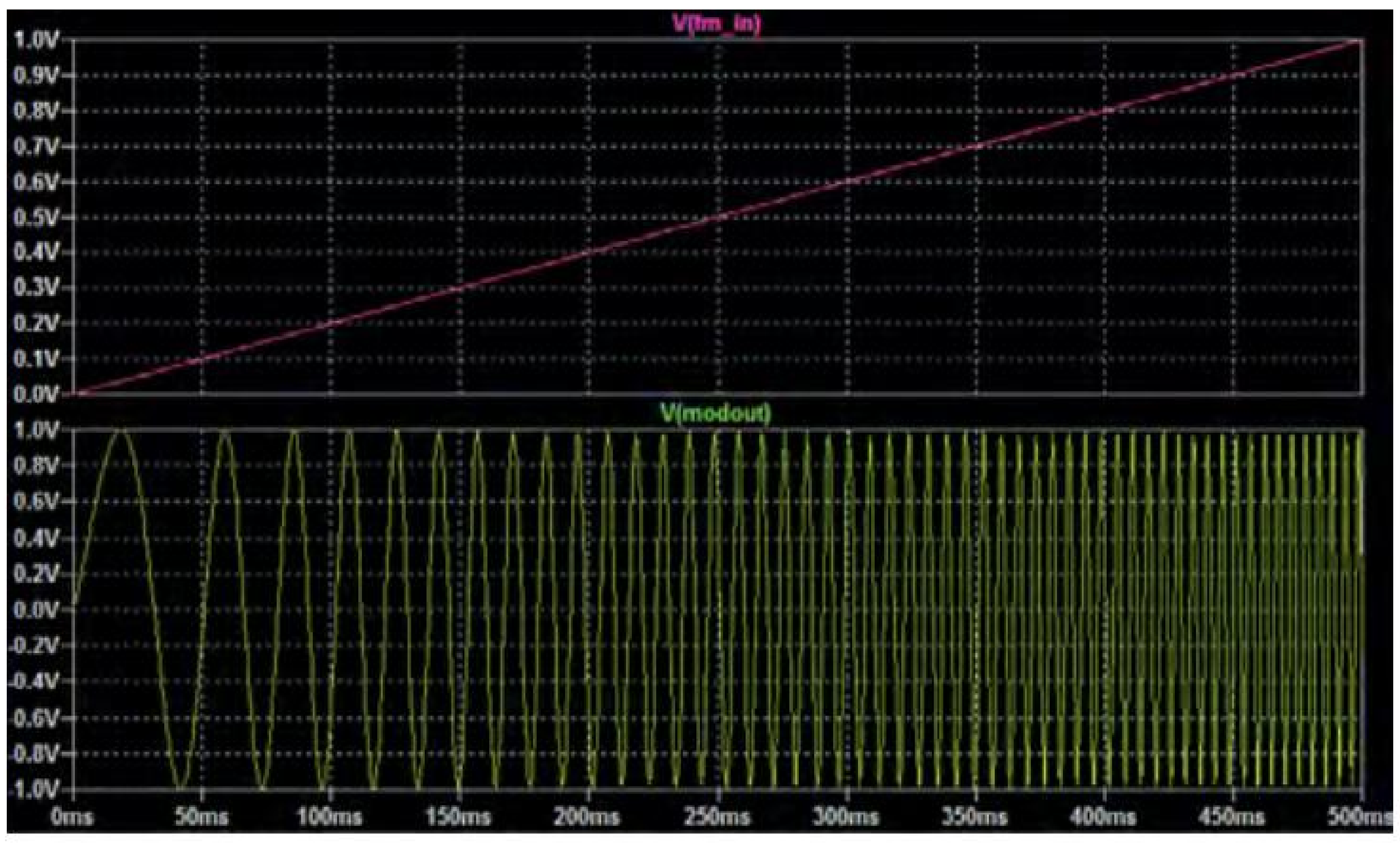


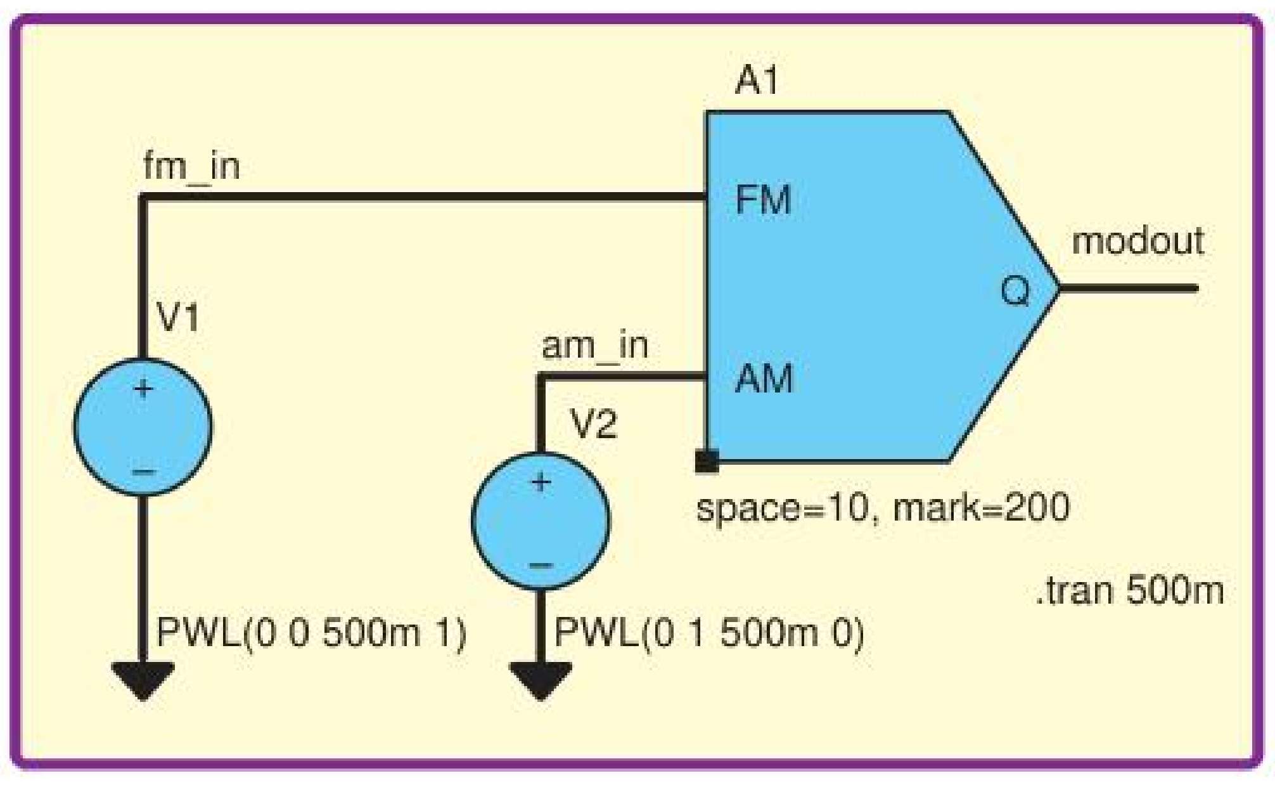
Fig.5. Results from simulating the circuit in Fig.3

Simulating amplitude modulation

The circuit in Fig.6 adds a control voltage to the AM input of the modulator. This is obtained from a similar PWL voltage source to the FM control, but with the voltage ramping from 1V down to 0V. The modulator's peak output voltage is set by the voltage on the AM input, so the output amplitude decreases linearly from 1V to 0V over 500ms in this example. The results of simulating the circuit in Fig.6 are shown in Fig.7.

The assumption is probably that the FM voltage should stay between 0V and 1V, but experiment shows that it continues to scale linearly for inputs above 1V. If the sign of the FM input is switched (eg, a switch from +1V to –1V) a phase shift occurs, but the frequency is set by the absolute value of the voltage, so remains the same. Switching the AM input negative causes the sign of the output to switch, which is what would (probably) be expected. This behaviour is illustrated by the circuit in Fig.8 and simulation results in Fig.9.

Fig.6. LTSpice circuit to demonstrate AM and FM action of the modulator



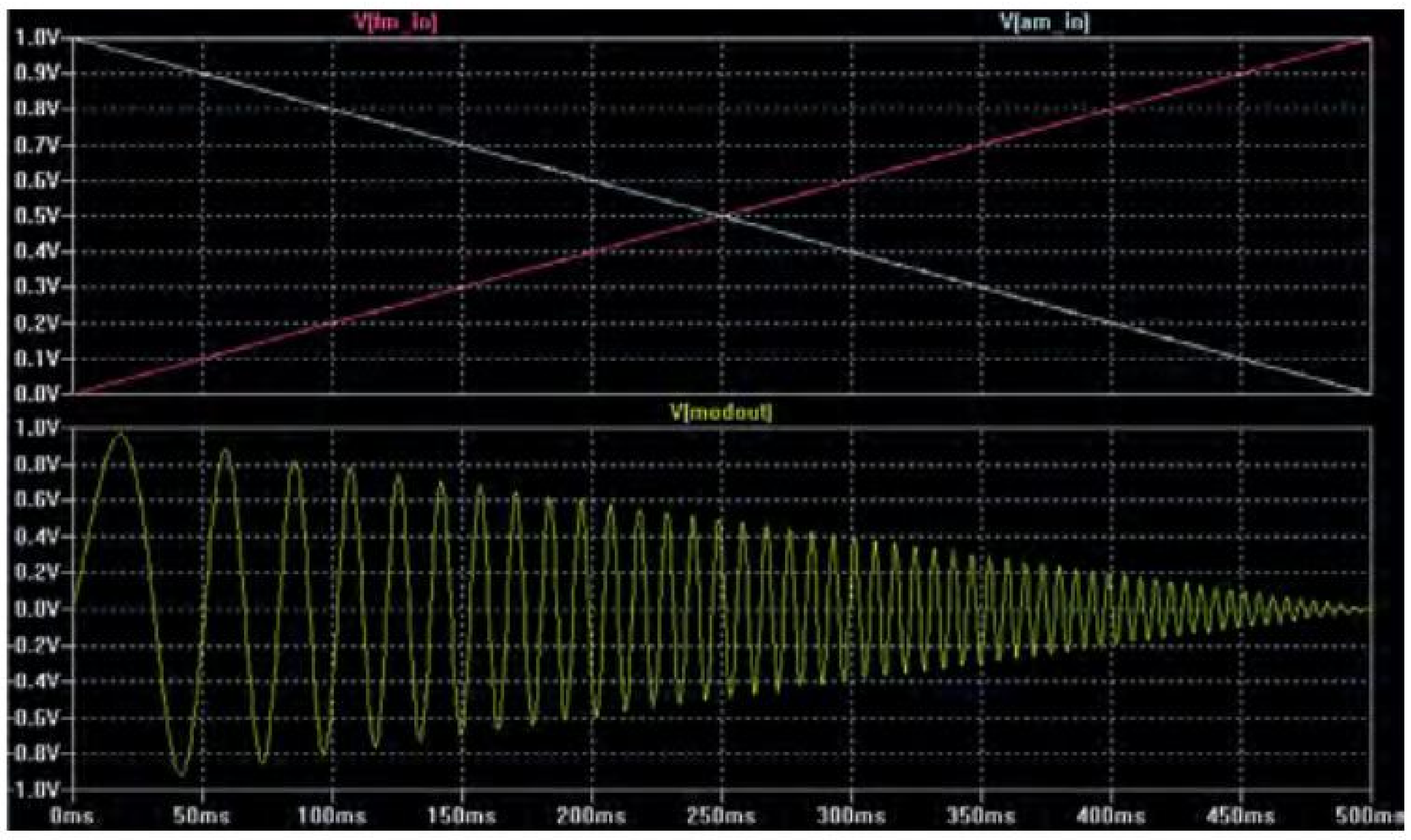
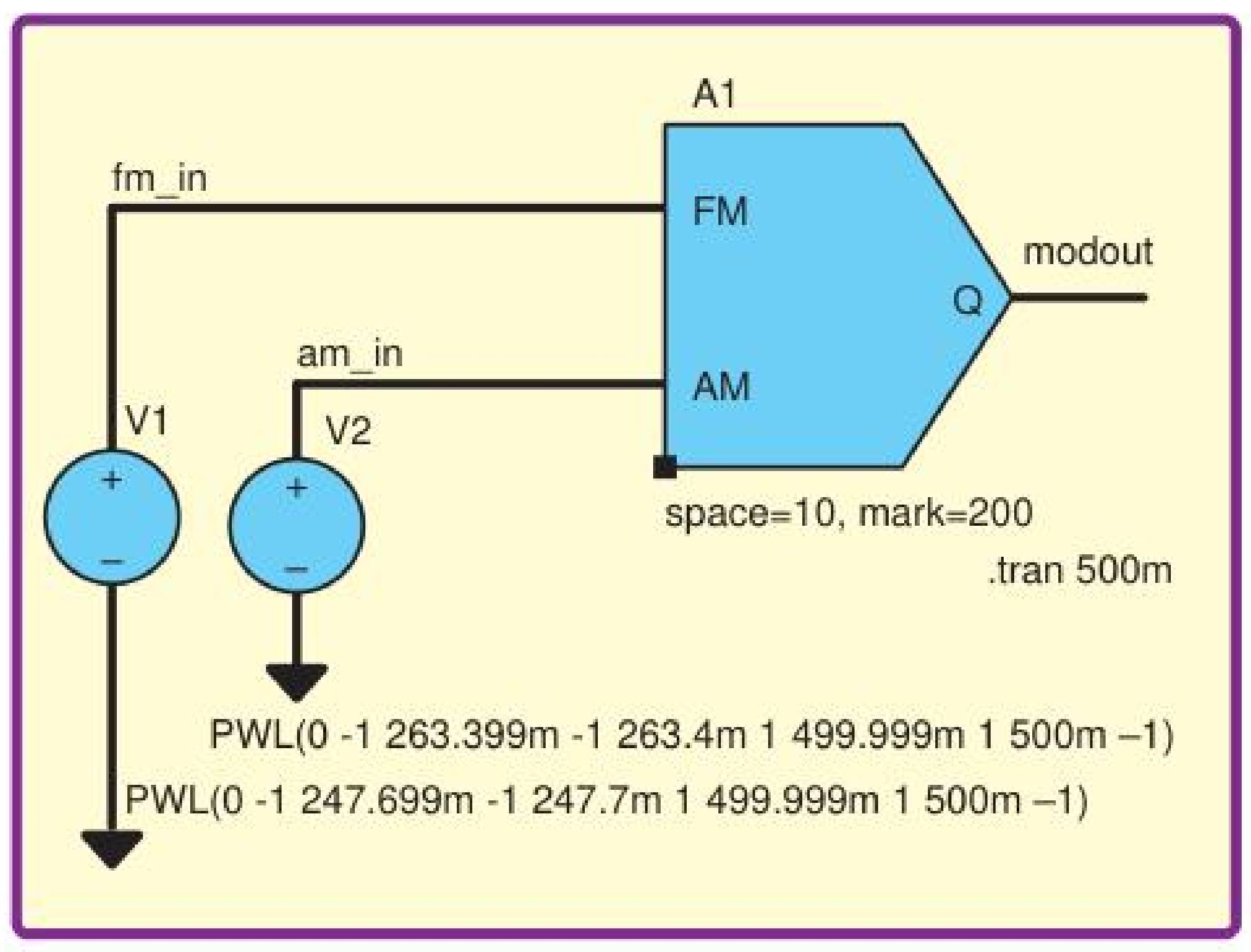


Fig.7. Results from simulating the circuit in Fig.6

Fig.8. Circuit to investigate modulator behaviour with negative control voltages


A1
fm_in
FM
modout
Q
am_in
AM
V1
V2
space=10, mark=200
.tran 500m
PWL(0 -1 263.399m -1 263.4m 1 499.999m 1 500m –1)
PWL(0 -1 247.699m -1 247.7m 1 499.999m 1 500m –1)

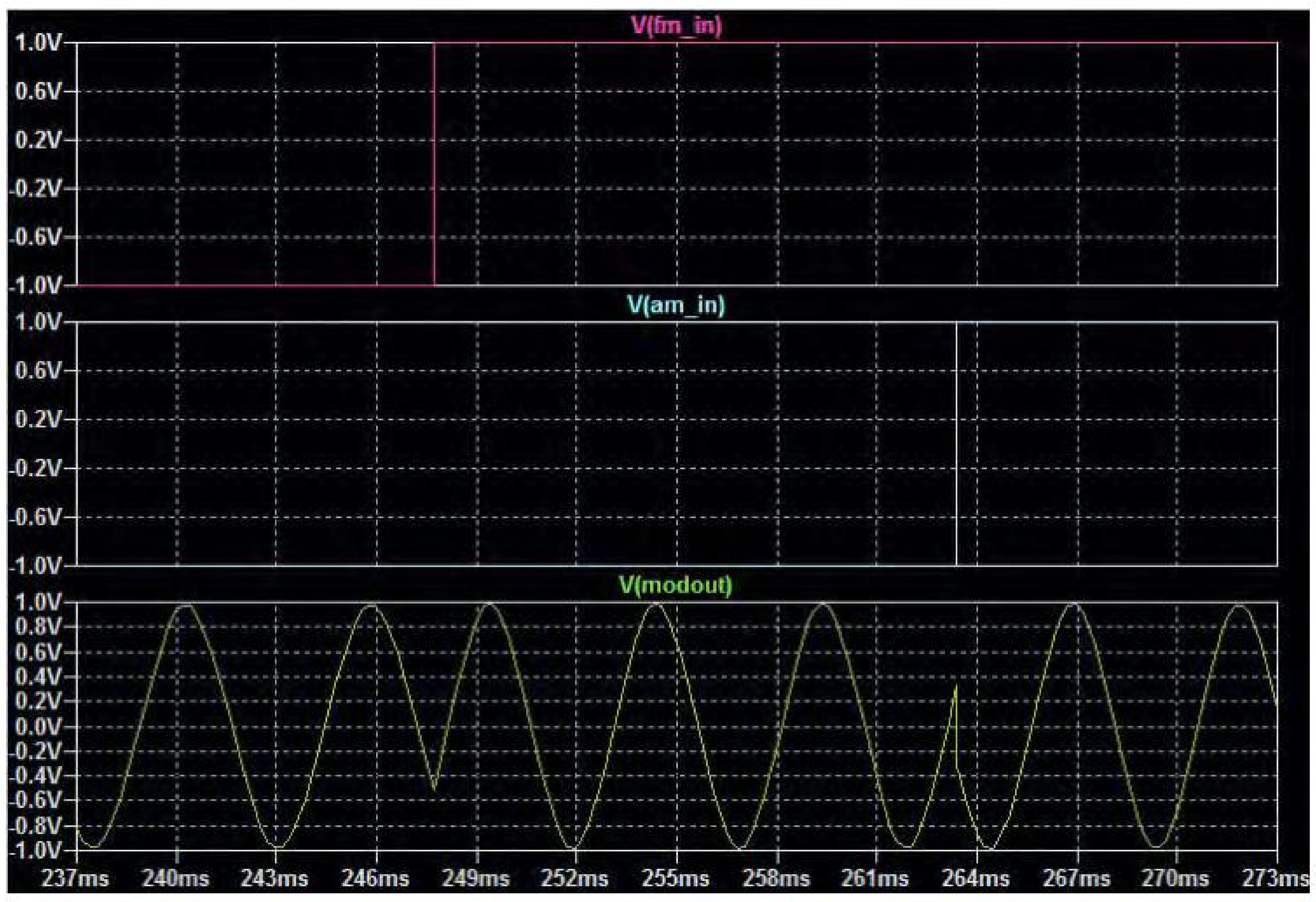


Fig.9. Modulator behaviour with negative control voltages

The behaviour with negative frequency control voltages is not too surprising, but it is not really specified in the help file. Another possibility would be to continue to linearly scale the frequency down from the Space value, at least until zero frequency is reached. This returns us to the issues of undocumented features, which we mentioned earlier. It is a hypothetical possibility (but unlikely) that Linear Technology could change the behaviour of the

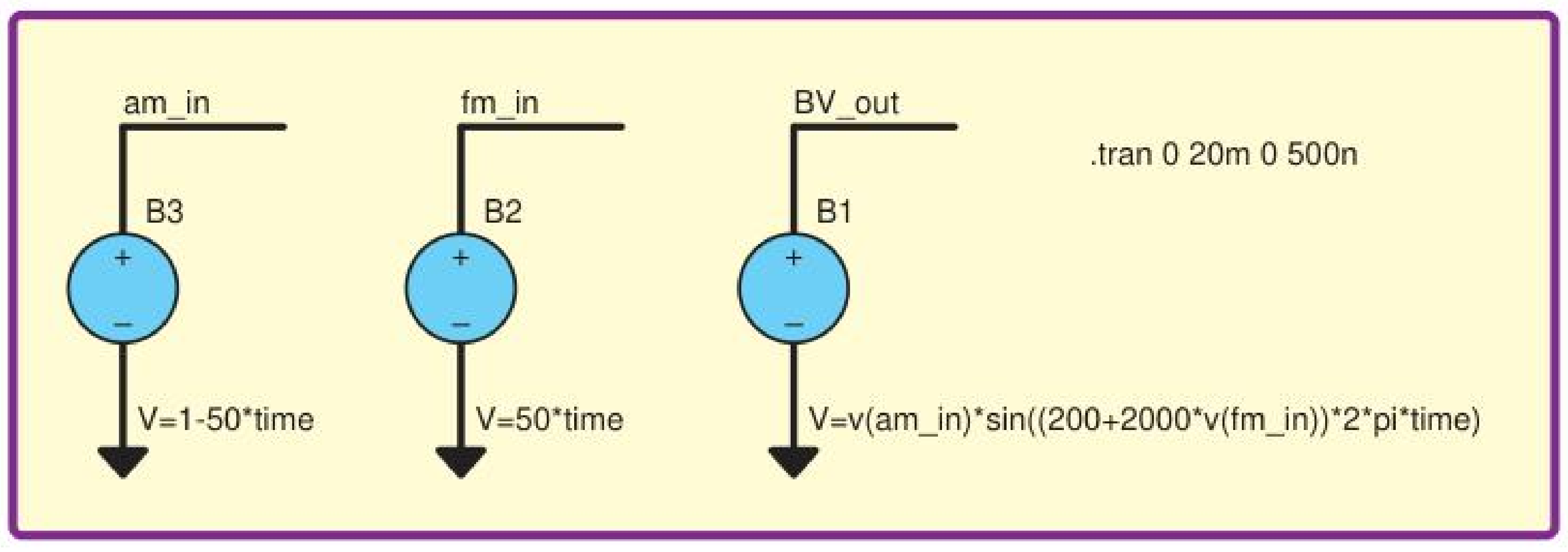


Fig.10. Frequency- and amplitude-modulated wave using a behaviour source

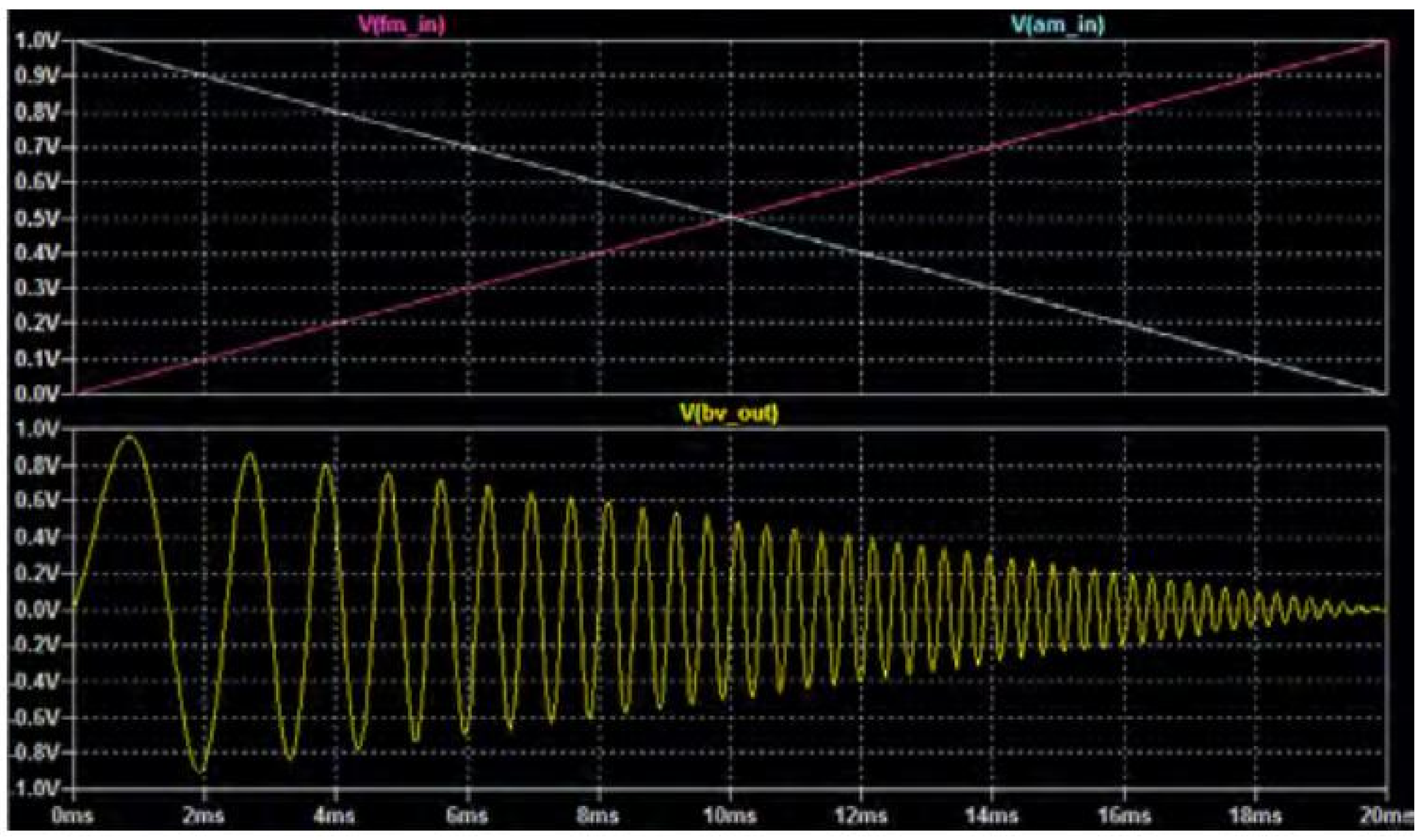


Fig.11. Results from simulating the circuit in Fig.10

modulator with negative FM inputs without changing the documentation. Anything relying on this may then stop working. Using undocumented features and behaviours can be useful and fun, but has its risks!

Behaviour source modulation

The modulator special function device is not the only way to produce FM/AM behaviour. It is also possible to use a behaviour source. These sources allow you to create voltages (and currents) which are based on mathematical functions of other circuit voltages and currents and simulation time. An example schematic is shown in Fig.10, with the results in Fig.11. Note that we have also used behaviour sources for the control voltage ramps, but PWL sources could also have been used for this. The output waveform has the same basic behaviour as the circuit in Fig.6, although the frequency parameters are different.

The disadvantage of this approach is that it is more complex to set up – you have to write the equation for the source (B1). Also, the schematic is perhaps harder to read. On the other hand, it is quite likely that Linear Technology has implemented the modulator more efficiently in special device form than if you replicate the behaviour with a B source. However, the advantage of using a behaviour source is that you have full control over its exact behaviour, within the limits of what is available from the maths functions associated with these sources.

The question from ***atferrari*** indicates that he would use the modulator to generate input signals to test a circuit. This is a perfectly valid use for it, for example to evaluate a circuit which processes signals of this kind – an FM demodulator would be an obvious case. The modulator device can also be used as a component in a larger system design. Linear Technology provides an example of this – a phase locked loop (PLL) which can be found in the example files provided as part of the LTSpice download (**PLL.asc** in the **\examples\Educational** folder of the install location). Behavioural models like this are useful to make sure that the basic operating principles of circuits and systems are correct before proceeding with a detailed design. It is worth pointing out that using the modulator as a test input signal generator is not ideal for evaluating frequency responses (eg, amplifiers and filters). For this task an AC analysis simulation should be use.

PLEASE TAKE NOTE

Our thanks go to eagle-eyed regular contributor Godfrey Manning for pointing out that we omitted an equation and diagram from the final page of Circuit Surgery, May 2015. Our apologies to readers – the missing items are reproduced here:

$$I_C = I_S\left[\exp\left(\frac{V_{BE}}{V_T}\right)-1\right]-\frac{I_S}{\alpha_R}\left[\exp\left(\frac{V_{BC}}{V_T}\right)-1\right]$$

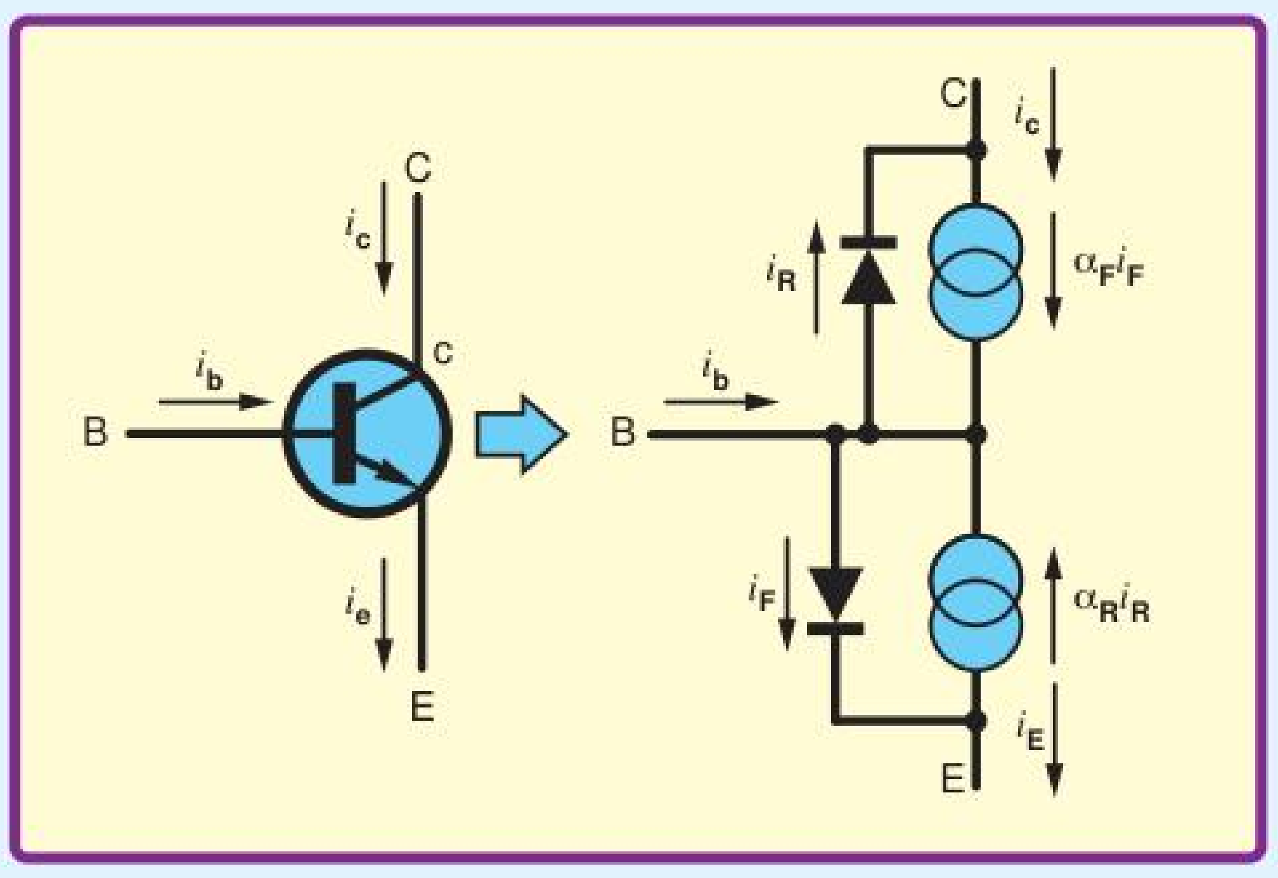


Fig.12. The classic Ebers-Moll full bipolar transistor model

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READOUT

Matt Pulzer addresses some of the general points readers have raised. Have you anything interesting to say? Drop us a line!

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☆ LETTER OF THE MONTH ☆

Powerful praise

Dear editor
I have been searching the internet for information about the difference between neutral and earth (ground) when, after at least an hour of viewing some confusing rubbish, much of it relating to the US system, I was fortunate to find your description at: **www.epemag.net/electricity-generation6.html**

Having worked in industry in instrumentation, control and automation, I am now retired – but still a 'techie' at heart. I have some understanding of our electrical generation and distribution system – many years ago I was actually taught the basics at college – but, I had mistakenly got it into my head that the transformers that reduce the 11kV supply to 415V had star primary windings and delta secondary windings. At the same time I knew, correctly, that the 'neutral' was the transformer's star point connected to earth (ground) at the substation.

What I could not understand was how connecting the star point of the transformer primary to earth would provide a neutral for the single-phase circuits connected to the transformer secondary. Thanks to your excellent article I have now had many years of misunderstanding corrected. My search directed me directly to page five of your online article, but I am now going to read all six pages from the start.

It must seem a bit strange to receive an email out of the blue from a complete stranger, but I just thought I would let you know that your explanations are very interesting. Far too many people do not realise the work involved in providing us with all the basic services that are taken for granted, but are quick to complain when those services fail due to breakdowns.

Brian Williamson, by email

Alan Winstanley replies:
It was very kind of you to drop us a line – in fact, we regularly receive emails 'out of the blue' and enjoy reading and responding to them! The online resource you mention is a web-enabled reprint of my short series about power generation entitled, From Pipelines To Pylons *that appeared in the August and September 1999 editions of* EPE. *I gained unfettered access to a power station at the time and it quickly became an immensely satisfying and absorbing project to tackle.*

It seems I hit a sweet spot, as the article is still referenced by various teaching and training establishments to this day, and I'm glad to have managed to reproduce it on the web. I also fully agree that many people are very unforgiving and take our electricity supplies for granted. We enjoy near-uninterrupted supplies through all weathers thanks to the gargantuan efforts of the men and women who work in Britain's power generation sector and keep us safely and reliably supplied with electricity and gas.

Flashing Betty and plant potential

Dear editor
I was delighted to read in March's *Read Out* about *Betty's Flasher*, one of my small designs.

Also of particular interest to me was April's *Techno Talk* (see: *Electric bacteria*) by Mark Nelson. Through my own experiments, I have discovered that there is about a 0.4V potential between any plant and earth. Therefore, if several pot-plants are wired in series, they will power micro-power devices. If they are wired in parallel, then the use of a common ground means one will not obtain a voltage higher than 0.4V. While I succeeded in powering a germanium oscillator off plants in parallel, I was unable to harness this for any useful diode pump (ie, power supply). Further, there is a high degree of insulation between a plant and earth. This means that one can use grass as the sensor for a capacitive body detector, such as those I have previously designed.

A project with which I have made some progress, but have not yet successfully completed, is to give plants 'a voice' by converting their electrical signals to sound. I was thwarted by a combination of subtle electrical activity on the one hand, and wild voltage swings on the other.

Thomas Scarborough, in Cape Town

Matt Pulzer replies:
As always, good to hear from you Thomas. I look forward to hearing about a 21st century South African bush-powered radio!

POD publishing

Dear editor
Just an expansion to the Print-on-Demand (POD) book comments in Alan Winstanley's *Net Work* (May 2015).

What Alan says about POD is largely the case – but I feel he undersells the idea.

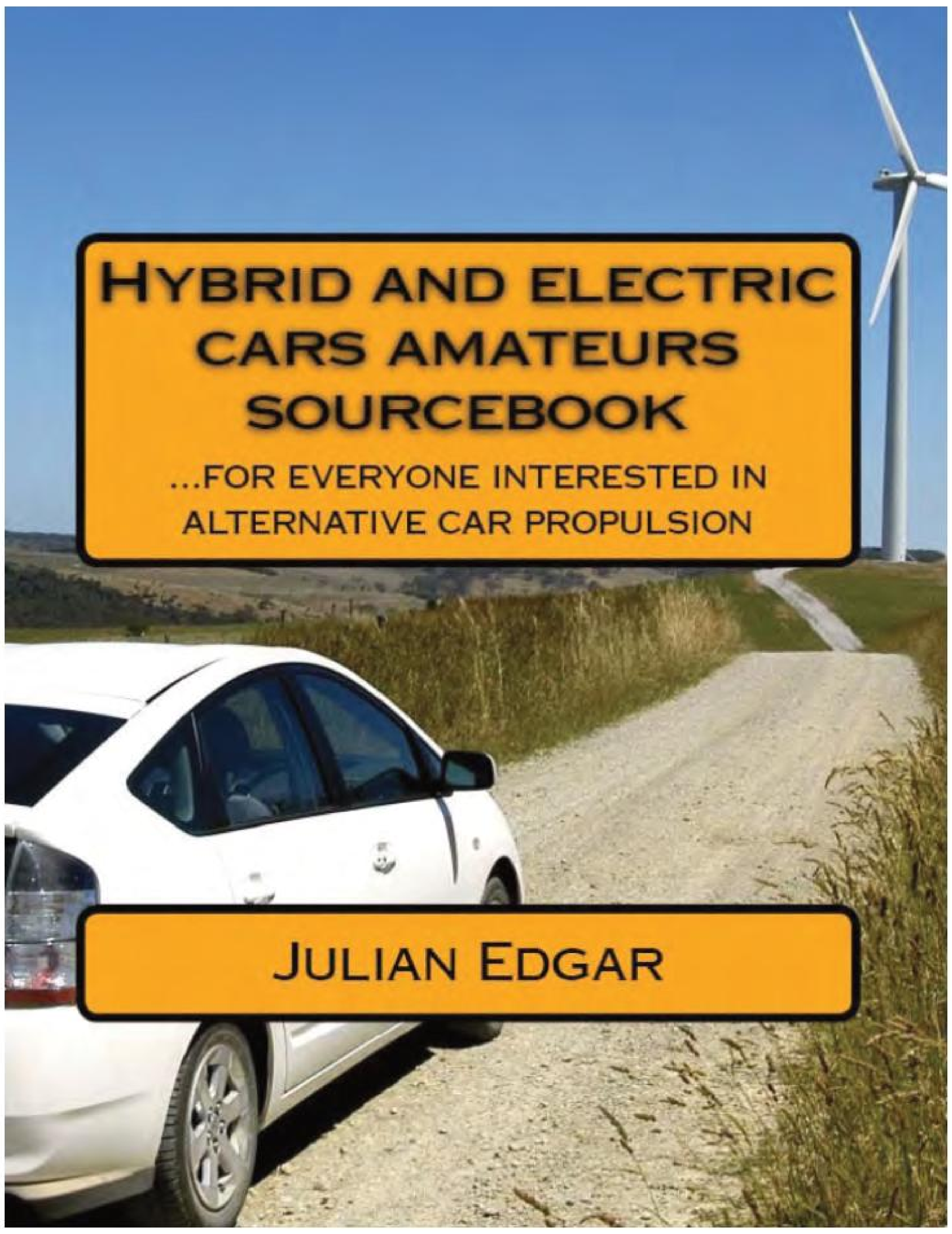
I currently have nine of my books available through Amazon (and some other resellers), published via CreateSpace. The books can be published at literally zero cost to the author – if you choose to proof the book on-line and not via a hard copy, you pay absolutely nothing to get your book published. Because you can set (within boundaries) the retail cost of the book, you can also effectively specify what royalties you receive. Having previously published books with mainstream publishers, I can say that the royalty-via-the-CreateSpace system is many times the royalty you receive from a traditional publisher.

The trick of course is to then sell lots of copies of that book – something that may be hard to achieve if you are writing books primarily to make money. (But they even let you, the author, buy copies cheaply, and then sell them however you like.)

POD through companies like CreateSpace allows you to publish that book you've always wanted to write – at no charge at all. After you have written and submitted the properly formatted PDF, and have designed the cover using the online design tools available on the site, you as the author need do nothing further. People can buy copies from Amazon (or can order it at bookshops), and you get paid.

I must admit that for the first book I published on CreateSpace I kept waiting for the 'catch', but there doesn't appear to be one.

Julian Edgar, by email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Alan Winstanley replies:
We both seem to agree that a POD publisher like CreateSpace is an ideal way of getting one's work into print, helped in no small way by Amazon's peerless marketing operation.

A CreateSpace book can also be sold into various academic, library or retail channels depending on what distribution rights the author decides to adopt – however, I did find this impacted very unfavourably on the cover price.

The unwelcome US IRS 30% Withholding Tax rules seem to be changing, and the outlook for non-US authors looks more promising. There is no doubt that web-based POD is a very liberating option for budding writers, and as I concluded in Net Work*, it has never been easier to get one's work into print than now.*

Old source code

Dear editor
I'm a graduate engineer developing health-care apps for the UK and German market. I've just discovered your fantastic publications (probably the best overall) and I will certainly buy *EPE* in the future.

I'm very interested in your *PIC Dual Channel VScope* project, which uses a PC's parallel port – even though the article dates from October 2000. Despite it's age, it suits my requirements and is exactly what I have been searching for.

However, I have one problem, I've not found the necessary HEX dump for the PIC 16f877 (?.OBJ). Can you help?

Fabien Wendlin, by email

Alan Winstanley replies:
Hi from EPE Magazine, and thank you for your kind commends and feedback about our projects.

Source code for old projects is hosted on the website: ***www.epemag.net****; go to:* ***www.epemag.net/microcontroller-code.htm***

The sections you need to visit are:
- *All PIC Microcontroller source codes*
- *PIC VScope October 2000 [original design]*
- *V2 PC Scope August 2007 [updated design]*

Please check carefully that ALL components are still available before constructing old projects like these. There were some difficulties with Version 1, so do check the ReadMe notes for information. In particular, do note the following:

> *'Since going to press with the* PIC Dual Channel VScope *(*EPE*, October 2000), the device specified for IC3, TC55257-DPL (and its alternative TC55257-DPI) has become obsolete.*
>
> *'The author has proved that the NEC device UPD43256 BCZ-70LL is a satisfactory replacement and is available from Electromail (the mail order division of RS Components Ltd.) as code number 265-465. It is also considerably cheaper.*
>
> *'Do not attempt to use any other variant of the TC55257 as it may have a different pin configuration.*
>
> *'John Becker,* EPE *Technical Editor (13 September 2000)'*

I am sorry that we cannot provide technical help with old projects like these – however, our forum at **www.chatzones.co.uk** *is a great place to ask for assistance from fellow* EPE *readers.*

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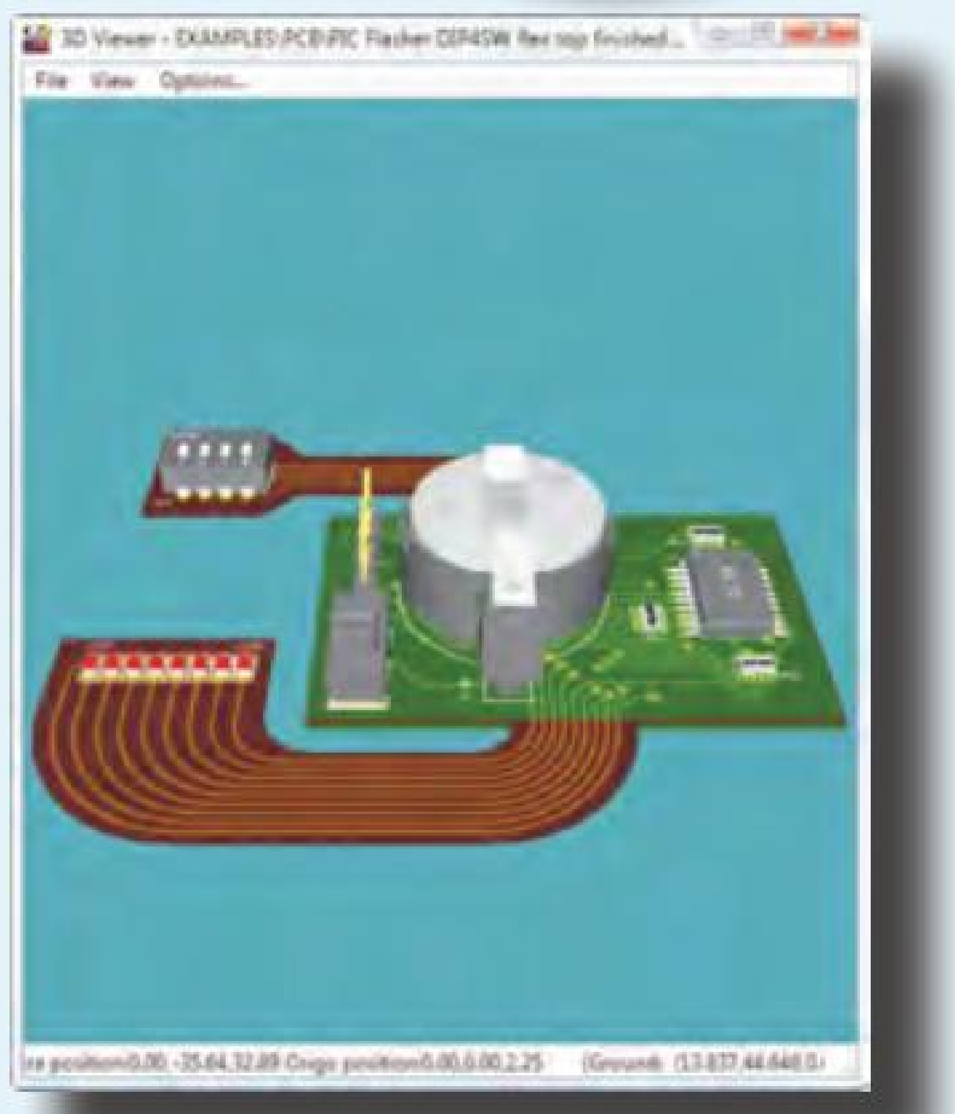

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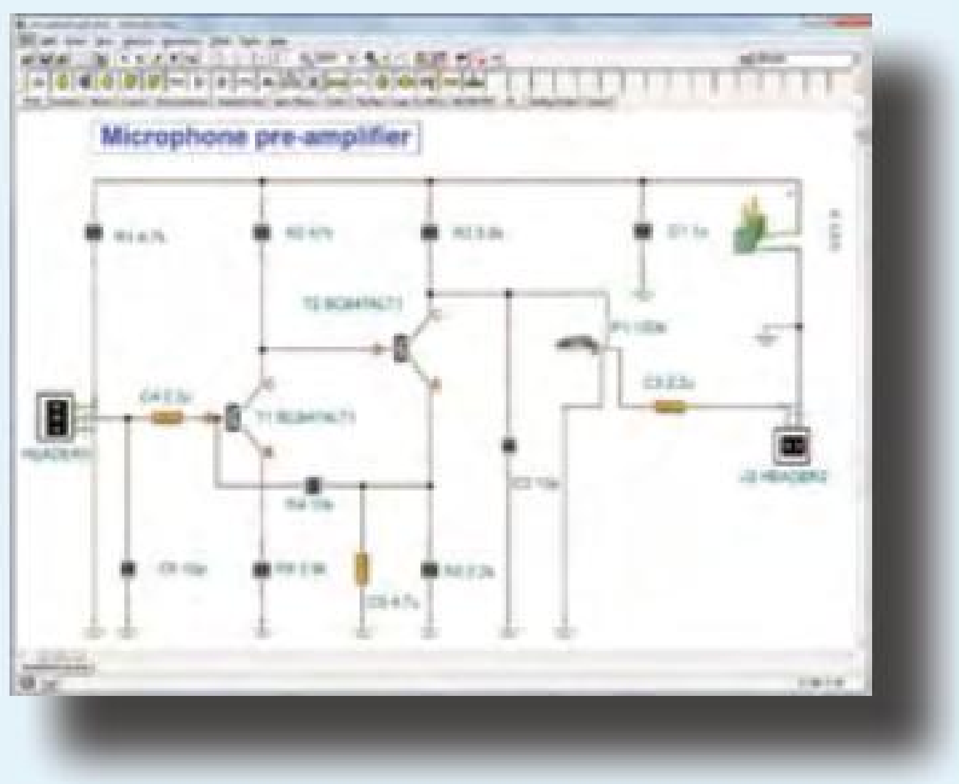

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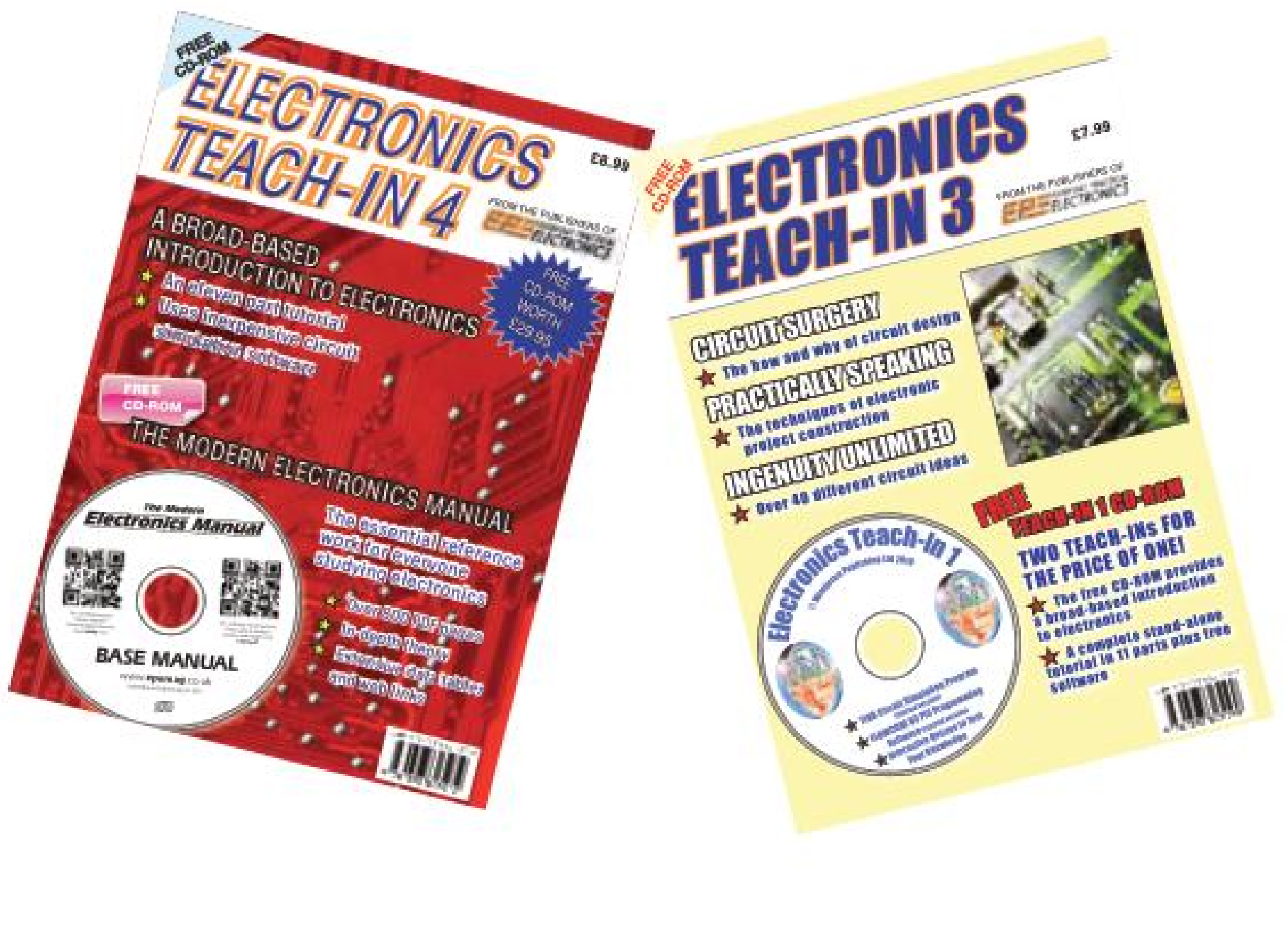

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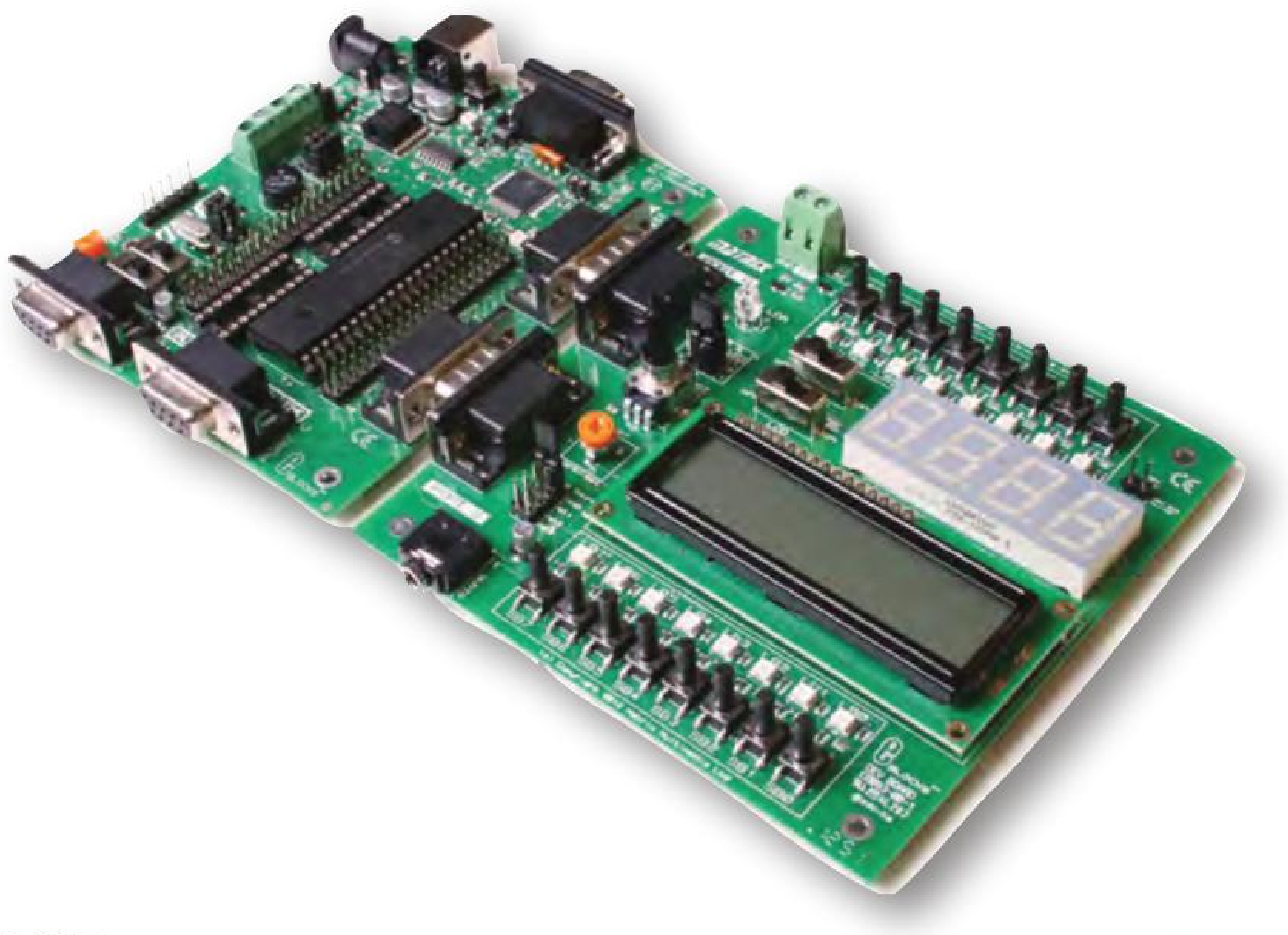

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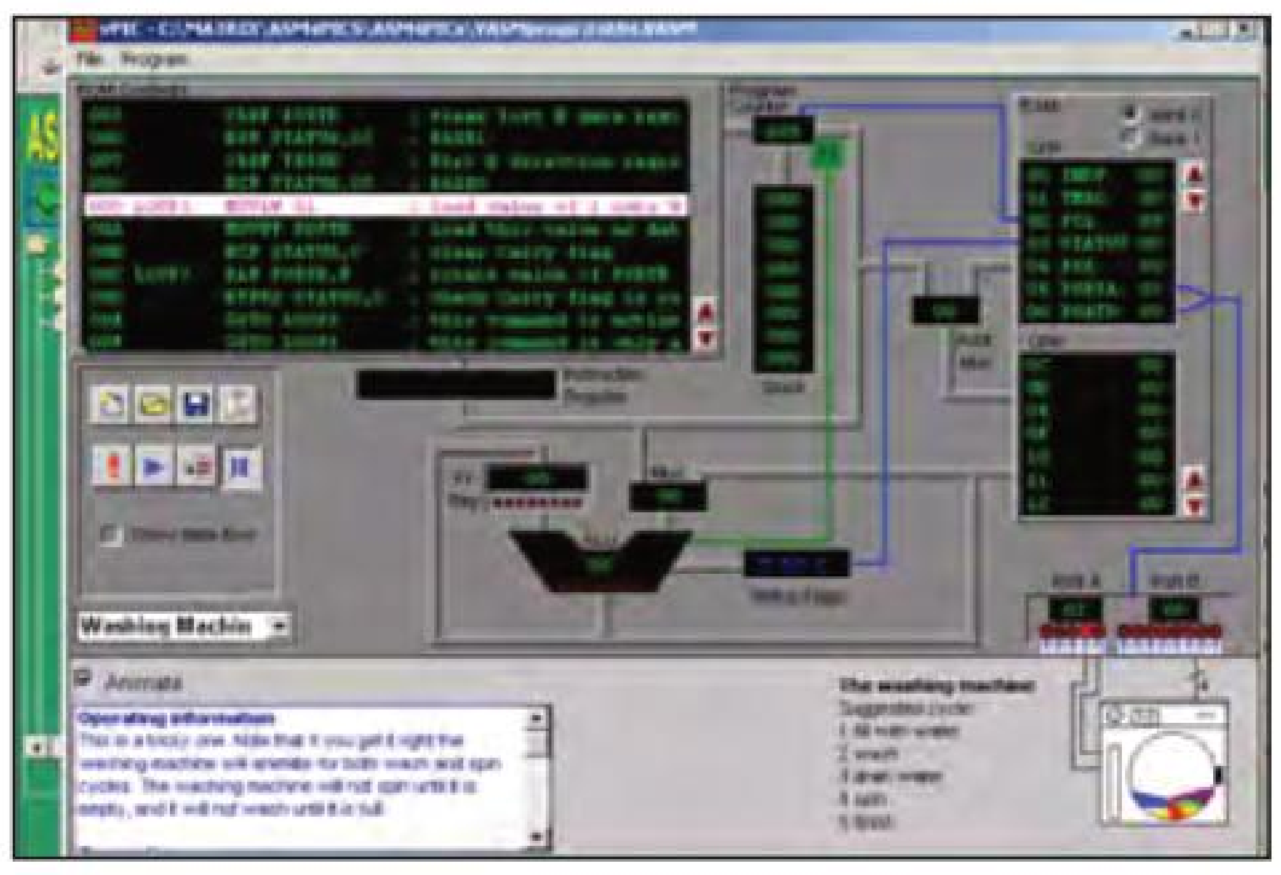

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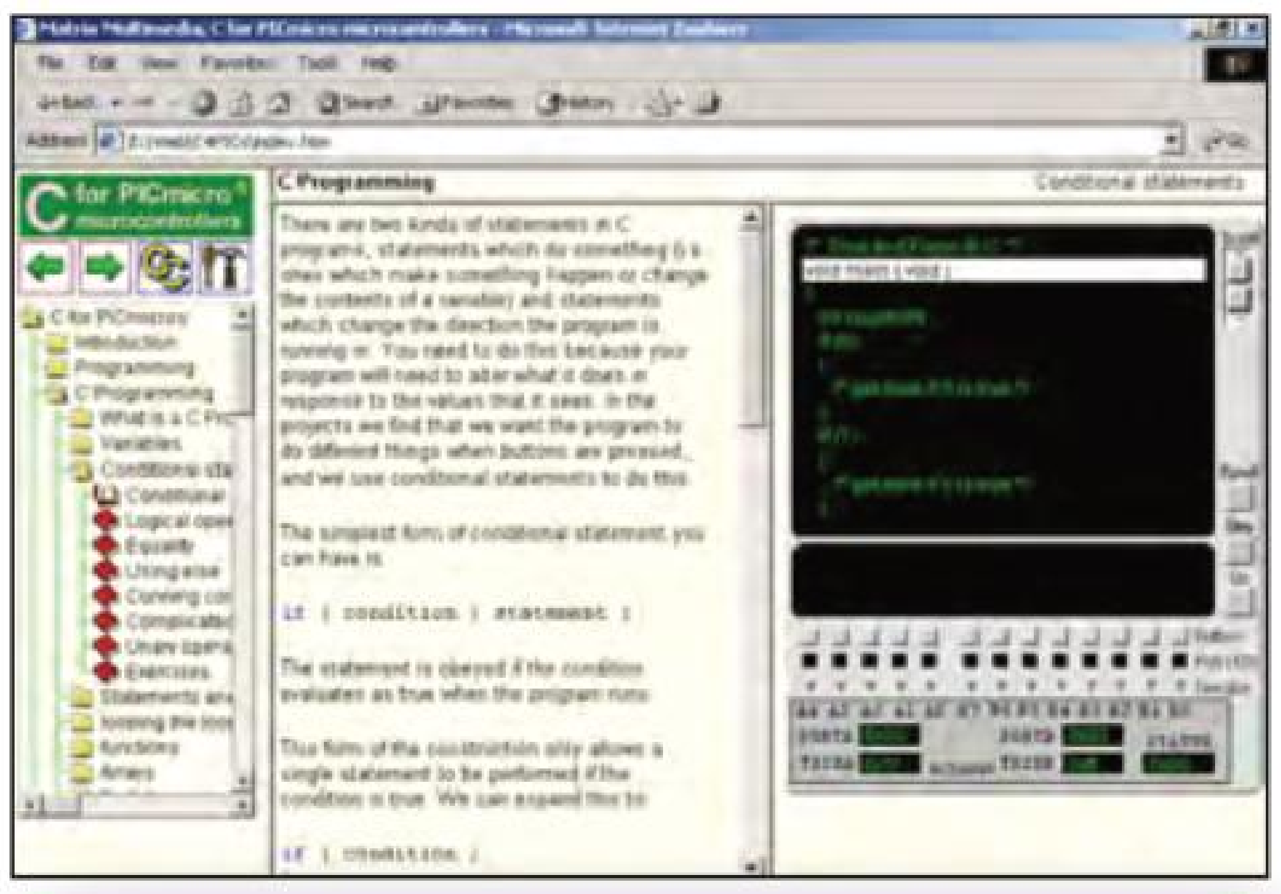

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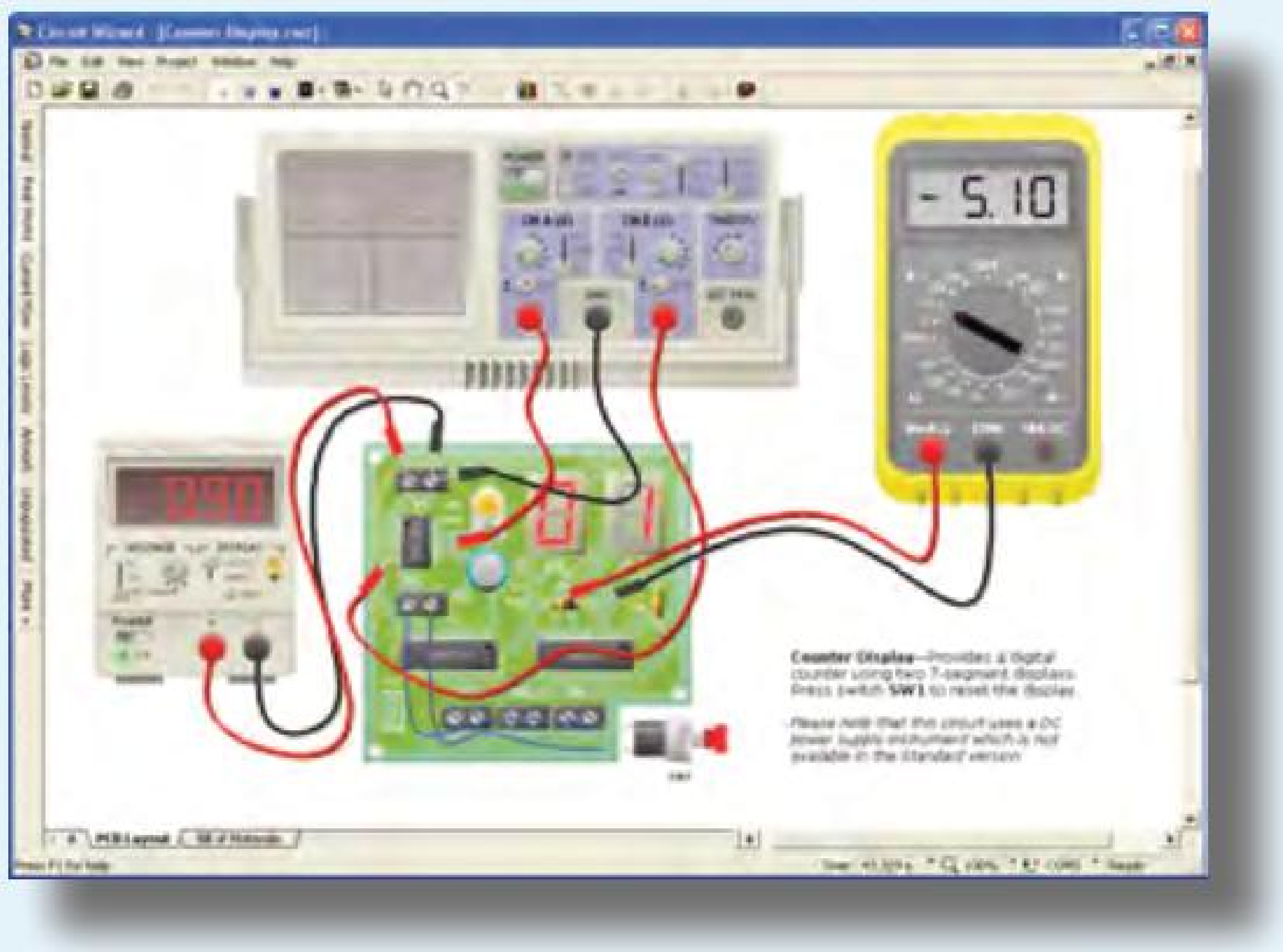

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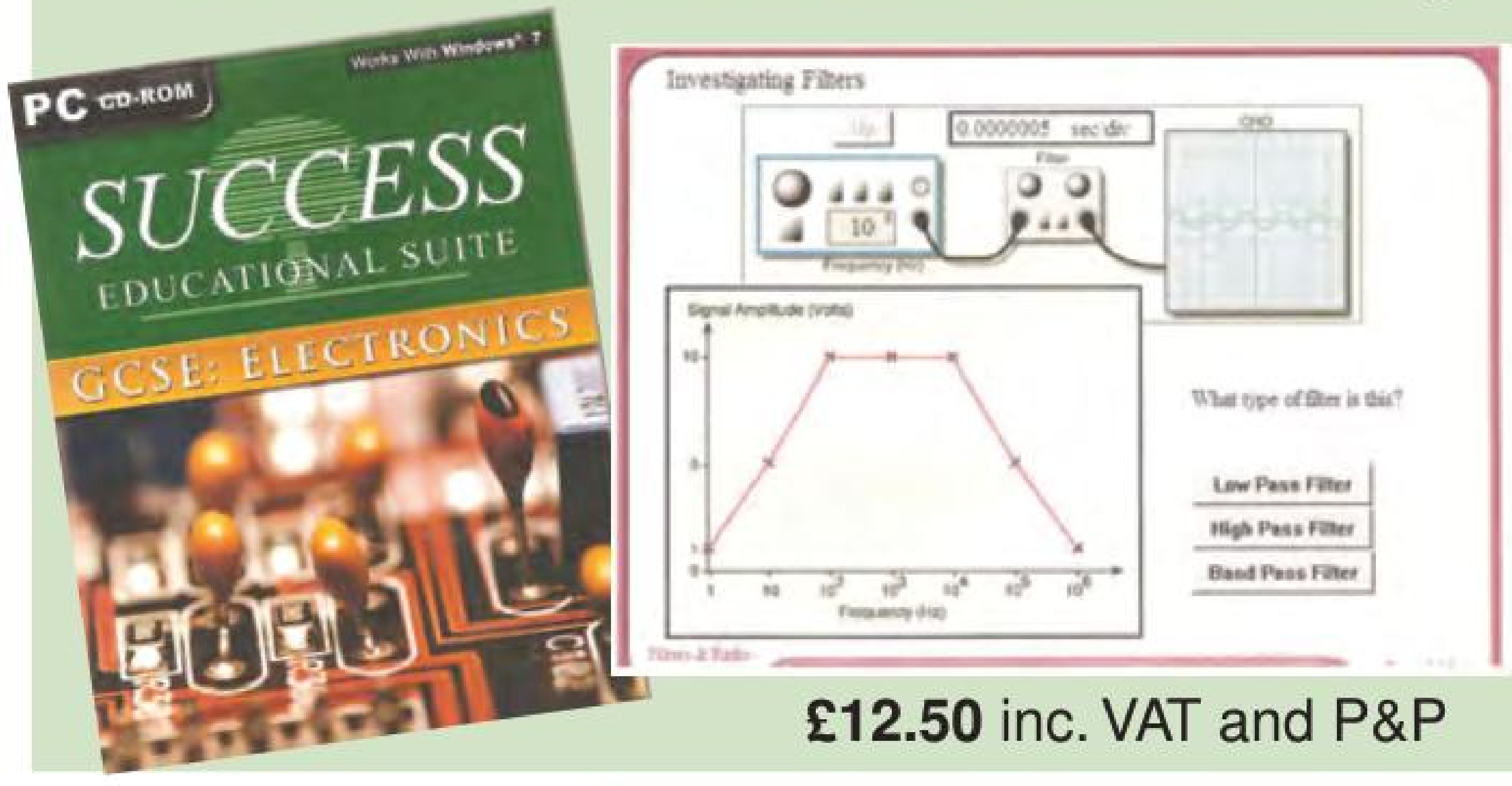

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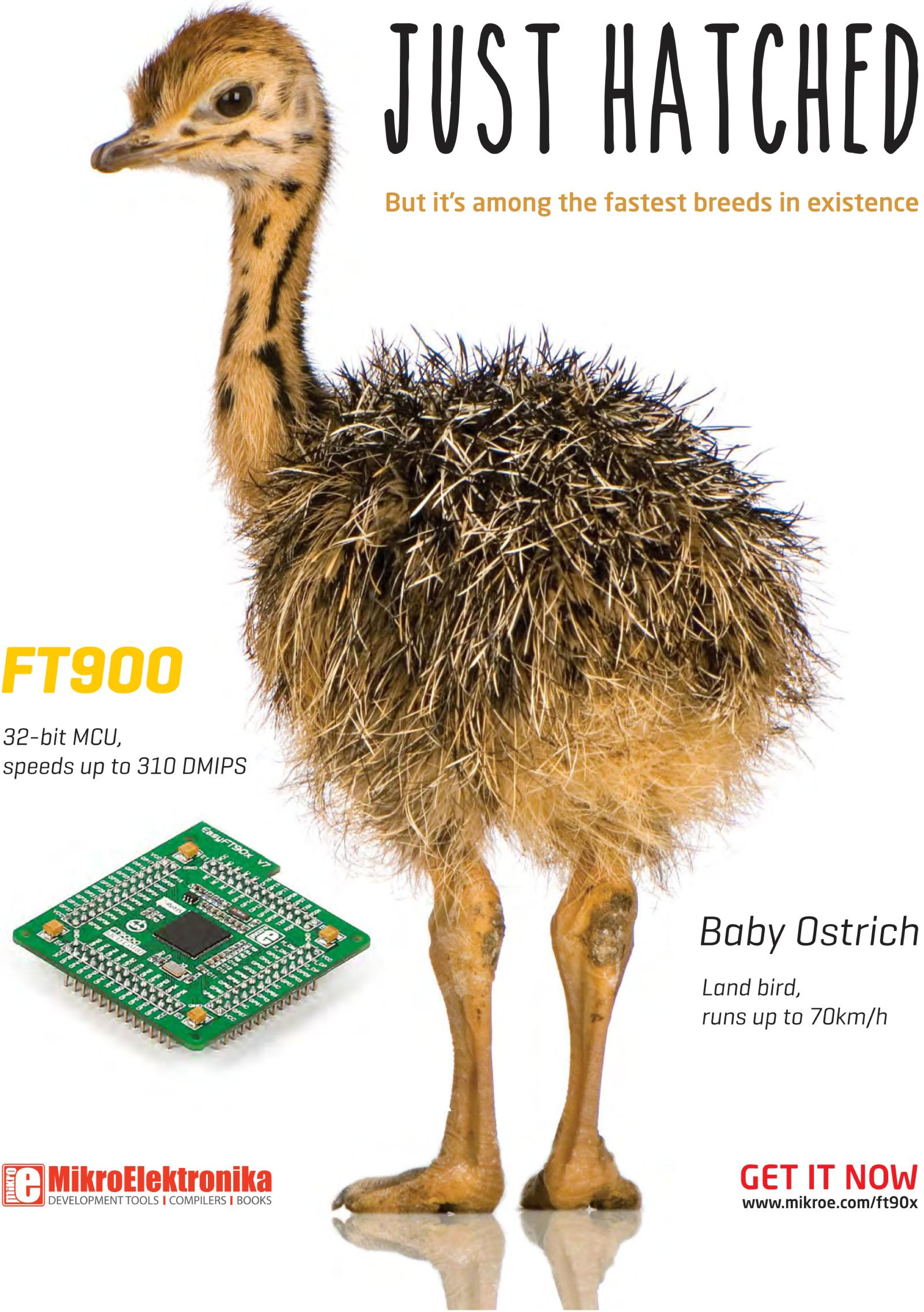

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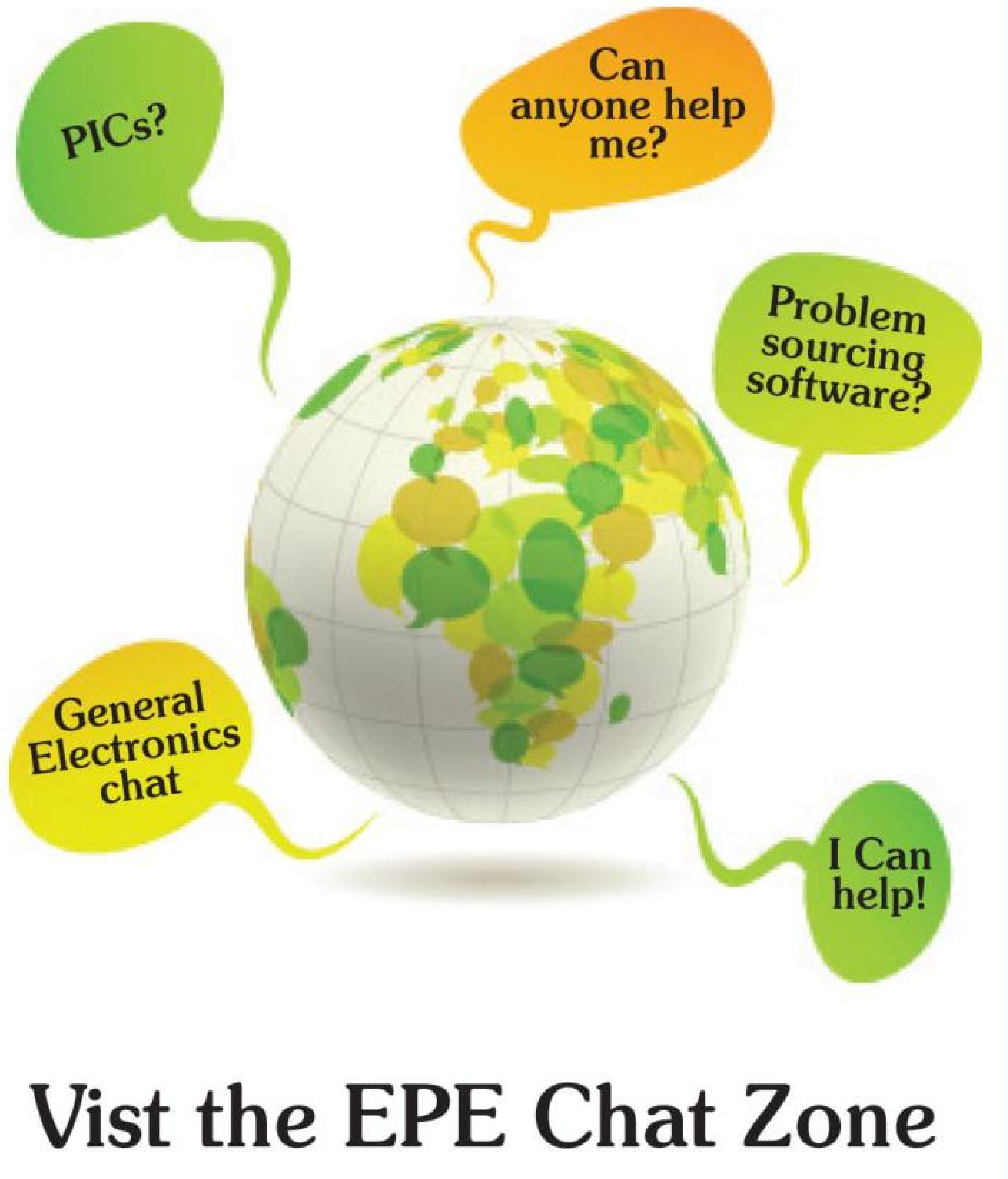
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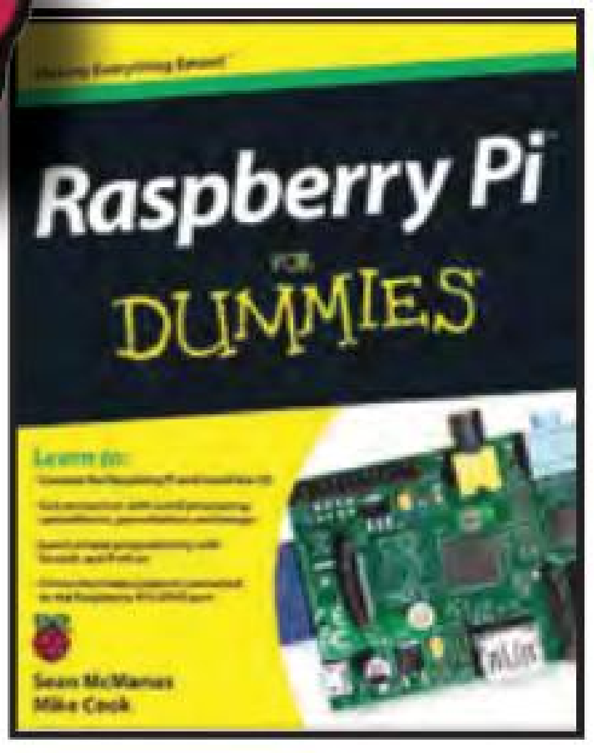

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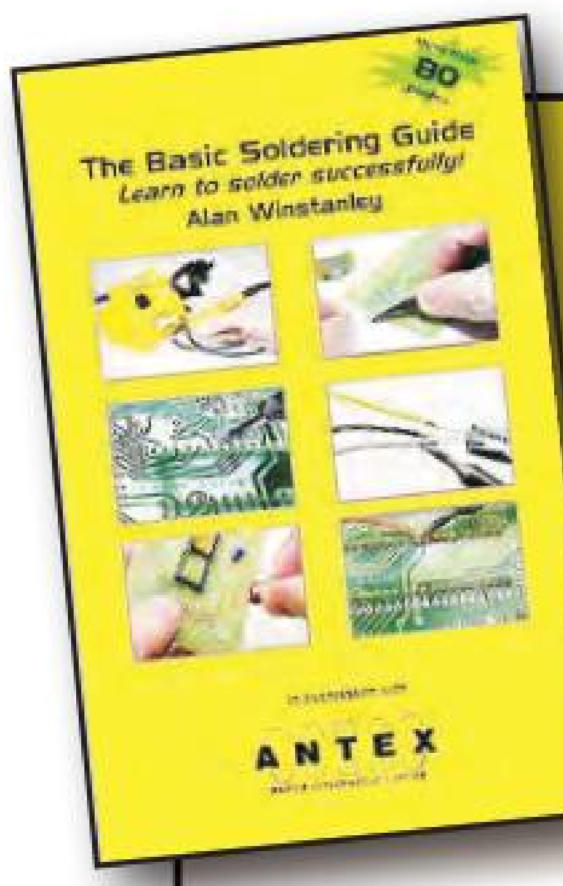

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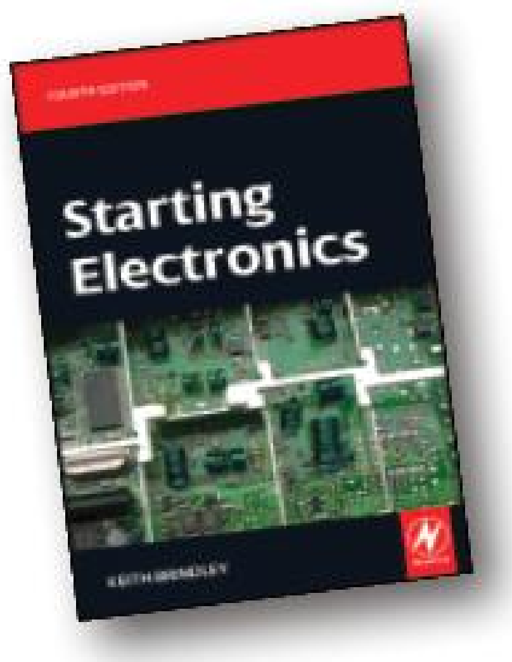

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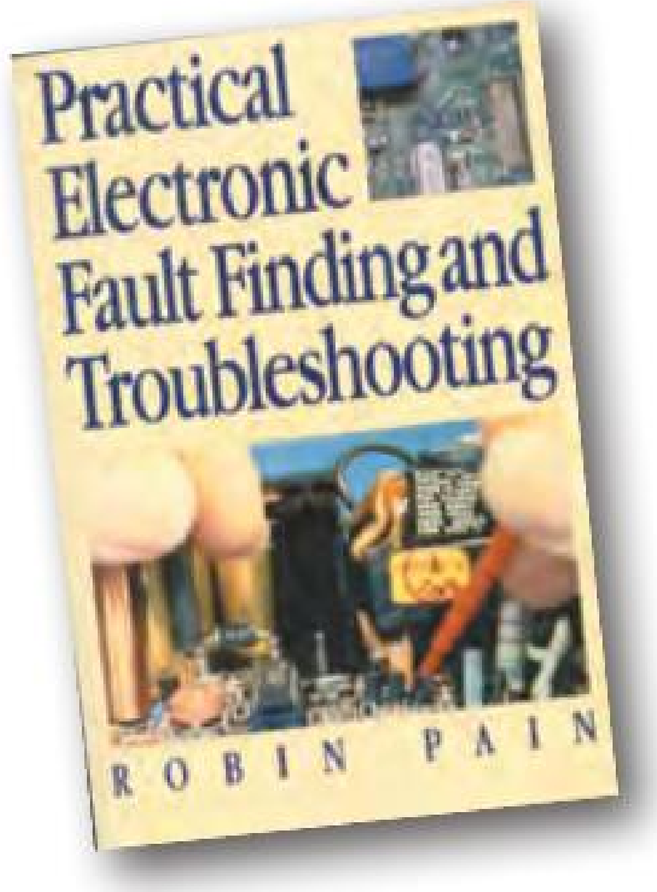

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Next Month

Resistor-Capacitor Decade Substitution Box

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Well, we know there are lots of valve enthusiasts out there who believe that valves are just better; much more musical and pleasant to listen to than those sterile solid-state circuits with oodles of negative feedback and vanishingly small harmonic distortion. Of course, valve amplifiers do have drawbacks, like heat and fragility, but what if you could get 'valve sound' from a solid-state state amplifier? Well now you can, with our *Nirvana Valve Sound Simulator*.

Teach-In 2015 – Part 7

In August's *Teach-In 2015*, we will describe the construction and use of a simple VU-meter. The *Discover* section will be devoted to heat sinks and heat sink design, while *Knowledge Base* will introduce you to some more circuit building blocks, including the differential amplifier, the current mirror and the V_{BE} multiplier.

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